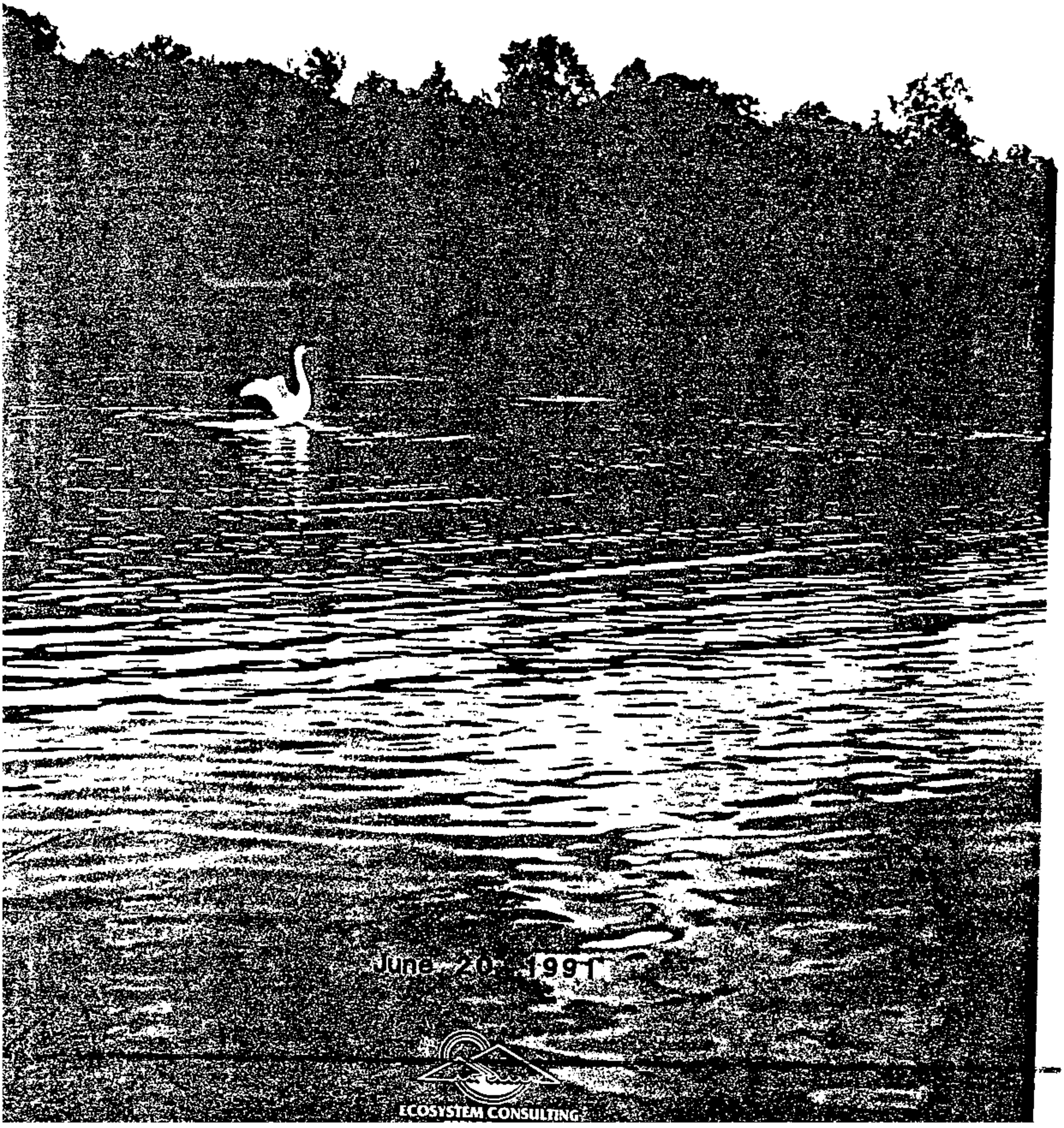
ROARING BROOK LAKE

Supplemental Diagnostic-Feasibility Study



June 20, 1991

ECOSYSTEM CONSULTING

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PREFACE

This report presents the findings and conclusions of a Supplemental Diagnostic Feasibility Study of Roaring Brook Lake For the Town of Putnam Valley, New York.

This report was prepared to assist the Roaring Brook Lake community to begin evaluating its lake management program. This study was initiated and planned based on the scope-of-work developed for the County Lake Grant Program. As the study progressed, several ecosystem characteristics were identified which were quite different from those anticipated based on previous investigations. Additional study items were added to ensure that this study provides adequate information to identify and evaluate management alternatives. Our primary goal is to facilitate informed management decisions by the lake community.

The purpose of this report is to:

1) describe what has been revealed by our study,

2) identify characteristics of the system which will be of management utility, and

3) allow the lake community to begin development of an effective, long-term management approach to control problem aspects (e.g., nuisance macrophytes).

The report begins in Section I with the watershed features and runoff characteristics. Section II is in-lake ecosystem structure and function including morphometry profile features and surface water survey. The macrophyte information is presented here, but is preliminary since it is not yet completed. The third section contains management suggestions.

Beginning each section is a short introduction containing general background information about that particular aspect of the study. This text is followed by a double dashed line (===). Specific information generated on Roaring Brook Lake follows this line and is double spaced.

The Watershed

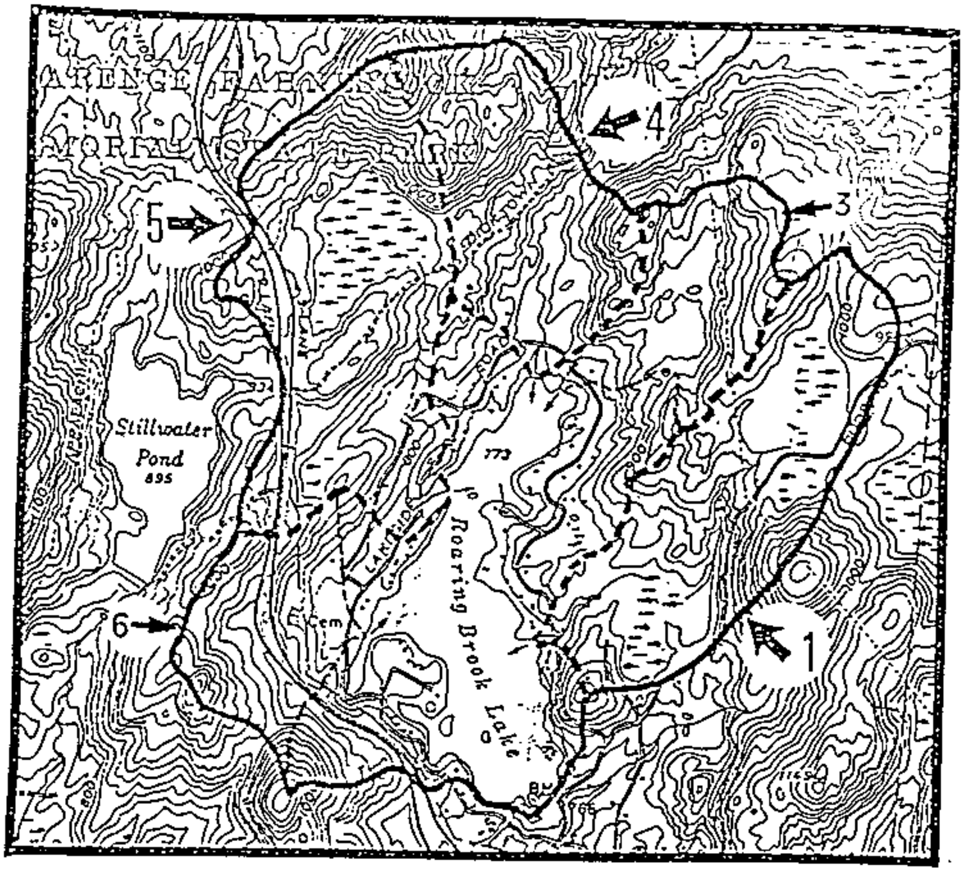
I. A. Watershed Features

The most effective approach to understanding lake eutrophication is to assess the flow of phosphorus from the watershed through the lake on an annual basis. Phosphorus is important in lake eutrophication because it is a limiting nutrient in most lakes. The reasons for this are severalfold. First, phosphorus appears to have a unique role in biochemistry which cannot be duplicated by any other atom. Second, phosphorus is a rather scarce element relative to the others needed in large amount by living organisms, i.e. carbon, hydrogen, oxygen, nitrogen, and sulfur. Finally, unlike other important nutrients, phosphorus has neither a gaseous phase nor a common gaseous compound. Unlike sulfur, for instance, phosphorus cannot form a gas such as hydrogen sulfide that can escape from lake sediments as bubbles. In fact, most compounds of phosphorus are insoluble as well as **non-volatile**. Once an atom of phosphorus has been covered by an inch or so of sediment, the probability of it again participating in lake ecosystem activity declines sharply.

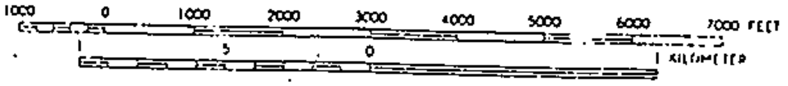
Quality of lake water depends upon natural characteristics of the drainage basin and upon uses for which the land has been employed by man. Research has shown that the amount of watershed phosphorus reaching a lake can be predicted from the size and shape of the lake, the volume of watershed discharge to the lake, and the fractions of watershed which are urbanized, agricultural, or left in natural vegetation. The greatest export of phosphorus comes from urban watersheds. Agricultural watersheds export only about a third as much phosphorus. Forested watersheds lose about one-fifth as much phosphorus as agricultural watersheds.

The drainage basin of Roaring Brook lake is illustrated in Figure 1. The area of the total basin (954 acres) is small relative to the area of lake (110 acres); the watershed to lake area ratio is 8.7. The drainage from the watershed enters the lake primarily through three inlets. These are identified in Figure 1 as #1, 4, and 5. The area of these three basins comprises 574 acres or 60% of the total drainage basin. Inlet stream sampling was focused on these streams. The 1988 Ecoscience Study labeled these inlets as stations 3, 4, and 5, respectively. Two smaller subbasins have also been delineated on Figure 1 as #3 and 6.

Figure 1



ROARING BROOK LAKE
Drainage Basin
Important Subbasins



CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

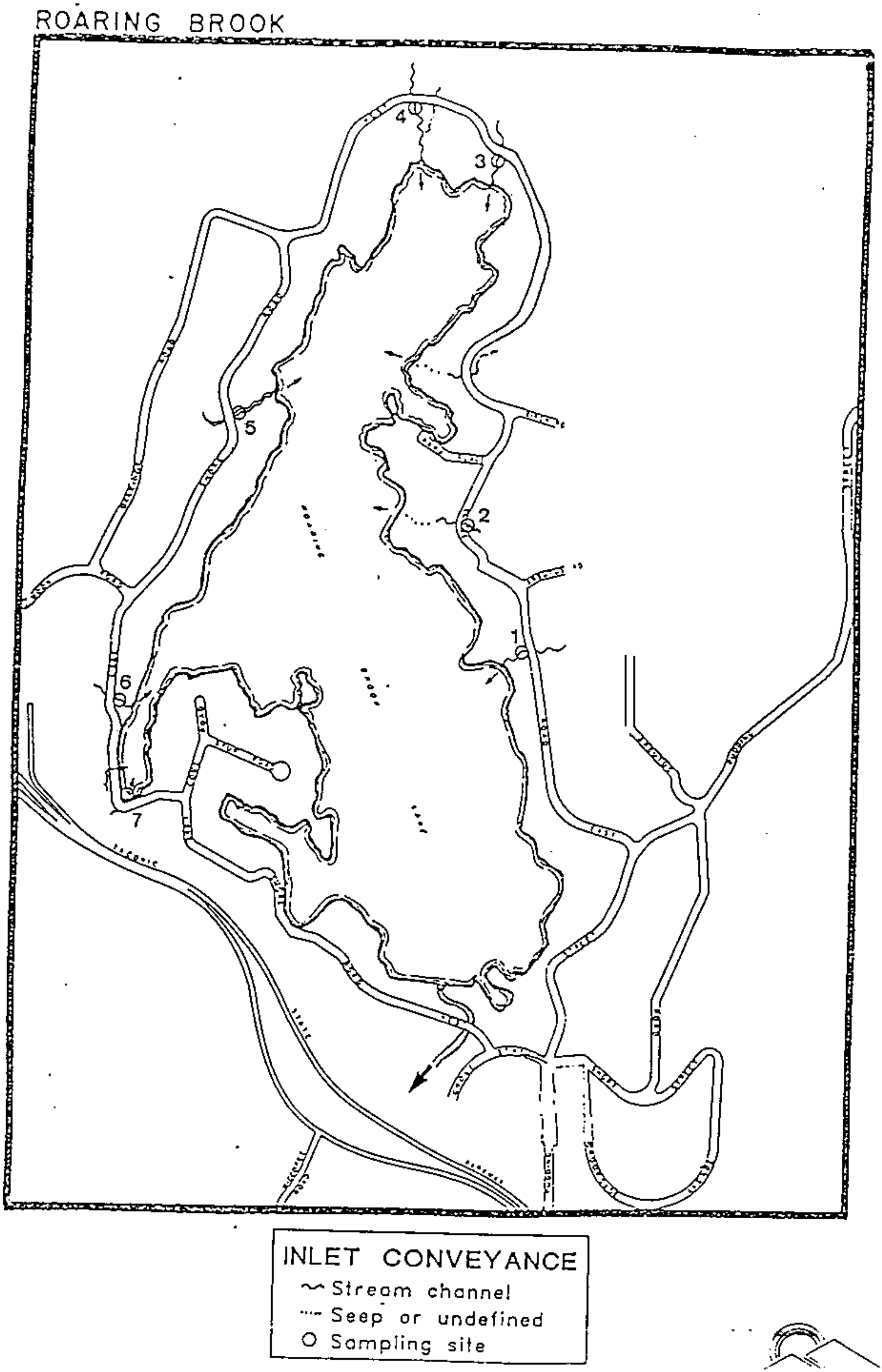
Streams draining these basins flowed intermittently. During the visits in 1990 (June 28 and August 17), these streams were dry. During the visit on April 18, 1991 the streams were flowing and were both sampled, as well as two additional inlet that did not previously have flow in them (#2 and 7). The boundaries of these two basins were not delineated. Because these basins are small and flow intermittently, actual contribution from them will be relatively low.

The sampling sites on these streams are shown in Figure 2. The nature of each inlet stream as it enters the lake is given. For the most part, all streams are composed of natural riffle pool or wetland stream channels. Only one culvert pipe was found to discharge directly into the lake. This is located between inlets #6 and 7. It was not flowing on any of the sampling visits and appears to be stormwater conveyance for street runoff in the immediate area.

The watershed contains very significant wetland areas in subbasins #1 and 5. These wetlands are most likely deciduous wooded swamps dominated by red maple. The wetlands influence the stream water flowing out of these basins by altering chemical parameters, generally toward lower pH and alkalinity and higher color (brown stain). Since these two inlets represent a large percentage of the inflow into the lake (roughly 50%), the composition of the lake water will reflect these characteristics.

The watershed also contains approximately 7000 ft. of the Taconic State Parkway. The highway runs along the western edge of the drainage basin principally in subbasins #5 and 6. The largest portion occurs in subbasin #5 where approximately 3300 ft. of

Figure 2


ROARING BROOK
4
3
5
2
1
6
7
INLET CONVEYANCE
~ Stream channel
···· Seep or undefined
○ Sampling site

highway lies on the western edge of the basin boundaries. In subbasin #6 approximately 2000 feet of highway runs through the middle of the basin. The remainder of the highway (1700 ft.) occurs in the southwest corner of the lake drainage basin and may drain in part to inlet #7.

In subbasin 5 the highway is remote from the lake occurring in the headwaters of streams flowing to the lake. There are also large wetland areas that may intercept stormwater runoff originating from the highway road surface, improving the water quality. These factors help mitigate possible contaminate loading to the lake from the highway. In subbasin 6 the highway is much closer to the lake, shortening the distance for possible remediation of the stormwater runoff. There are no large wetlands between the road and the lake as in subbasin 5. The contaminant loading effects of highway runoff may be evident in the water quality of inlet #6 because of the direct conveyance. The actual conveyance route from the highway to the lake needs to be determined in both these subbasins, but especially in #6. Storm flow from inlet 6 should be monitored for possible elevated levels of nutrients and other contaminates. The southwest corner of the lake drainage basin, the area that has not been delineated, should be investigated to determine the boundaries of inlet #7. Runoff from the highway in this area should be studied to determine conveyance. Because of the proximity of the highway to the lake, contaminant loading may be high. This inlet may need to be added to stormwater monitoring if it drains a significant area of the highway surface. Management of the stormwater runoff should be included in a long-term Lake Management Plan.

I.B. Watershed Hydrology

The ultimate source of lake water is precipitation. The first step in defining a lake's hydrology is to determine watershed area and multiply that area by the amount of effective rainfall to estimate how much water flows through the lake in an average year. In Connecticut one may reasonably assume an annual total rain and snow fall of 48 inches. About one half of this amount returns to the atmosphere as water vapor ("**evapotranspiration**"), and the balance ("**effective precipitation**") flows downhill as surface runoff or groundwater. Mean annual effective precipitation is about one half (24 inches) of total annual precipitation, but the proportion of effective to total precipitation varies seasonally due to changes in the water demands of terrestrial plant communities.

Mean precipitation is distributed very evenly throughout the year, but lakes receive most of their water between December and May because of water demands during the growing season by the terrestrial plant community.

The discharge of water from a drainage basin has a characteristic response pattern, called its "**unit hydrograph**", between the time precipitation occurs and the time runoff returns to pre-storm levels. The highest phosphorus content of runoff occurs in the part of the runoff hydrograph where flow increases most rapidly. At peak flow phosphorus concentrations begin to decline, and minimum concentrations occur at "**base flow**" when groundwater contributes most to discharge. A unit hydrograph when applied to a storm event (intensity and duration) can be used to construct a runoff hydrograph which tells the investigator what he is sampling and when he should sample it. By determining representative phosphorus concentrations for each flow stage of each lake inlet in each season of the year, one can convert inches of rainfall directly into net phosphorus delivered to the lake. The combination of unit hydrographs, rainfall/runoff relations, and efficient sampling at critical times is a reliable way to identify specific subbasins requiring nutrient control, to provide direct assessments of lake nutrient loading, and to accurately monitor progress in management.

Precipitation directly on the lake surface can be a significant portion of the lake's nutrient budget at certain times of the year. For instance, the fraction of total phosphorus and nitrate entering a lake from direct precipitation tends to increase in the summer when runoff is at a minimum. In contrast, atmospheric deposition of acids ("**acid rain**") accumulate with snow during the coldest part of the winter, and has the greatest effect on lake pH when the snow melts at ice-out and runoff is at a maximum.

Table 1 lists the estimated mean monthly runoff to Roaring Brook Lake on a 30-year rainfall-runoff record. The runoff coefficients used to generate this table were taken from the Lower Connecticut River Basin. Actual precipitation, antecedent precipitation, and rainfall-runoff characteristics of the watershed will modify these values. These data are useful to determine average flushing rate, refill rates for drawdown scenarios, etc. The estimated averages in Table 1 are presented graphically in Figure 3.

Table 1

ESTIMATED MEAN MONTHLY RUNOFF
TOTAL WATER BUDGET

Lake Name=	**ROARING BROOK LAKE**
Basin Identifier=	Entire Watershed including lake
Basin Drainage Area (acres) =	1063.61
Basin Drainage Area (sq. mi.)=	1.66
Mean Annual Streamflow (MGD) Per sq. mi.=	1.00
Mean Annual Streamflow (Million Gallons)=	606.59
Estimated Annual Runoff (acre-ft) =	1861.28

**************** **************** *************** ****************

Estimated Monthly Runoff Distribution

	of Annual Runoff	Mean Monthly Runoff acre-ft/month	cu ft/sec
January	10.04	186.91	3.14
February	8.71	162.12	2.72
March	16.50	307.11	5.16
April	16.79	312.51	5.25
May	10.58	196.92	3.31
June	6.67	124.15	2.09
July	3.75	69.80	1.17
August	3.45	64.21	1.08
September	3.45	64.21	1.08
October	4.04	75.20	1.26
November	7.29	135.69	2.28
December	8.66	161.19	2.71
Totals	99.93	1860.01	

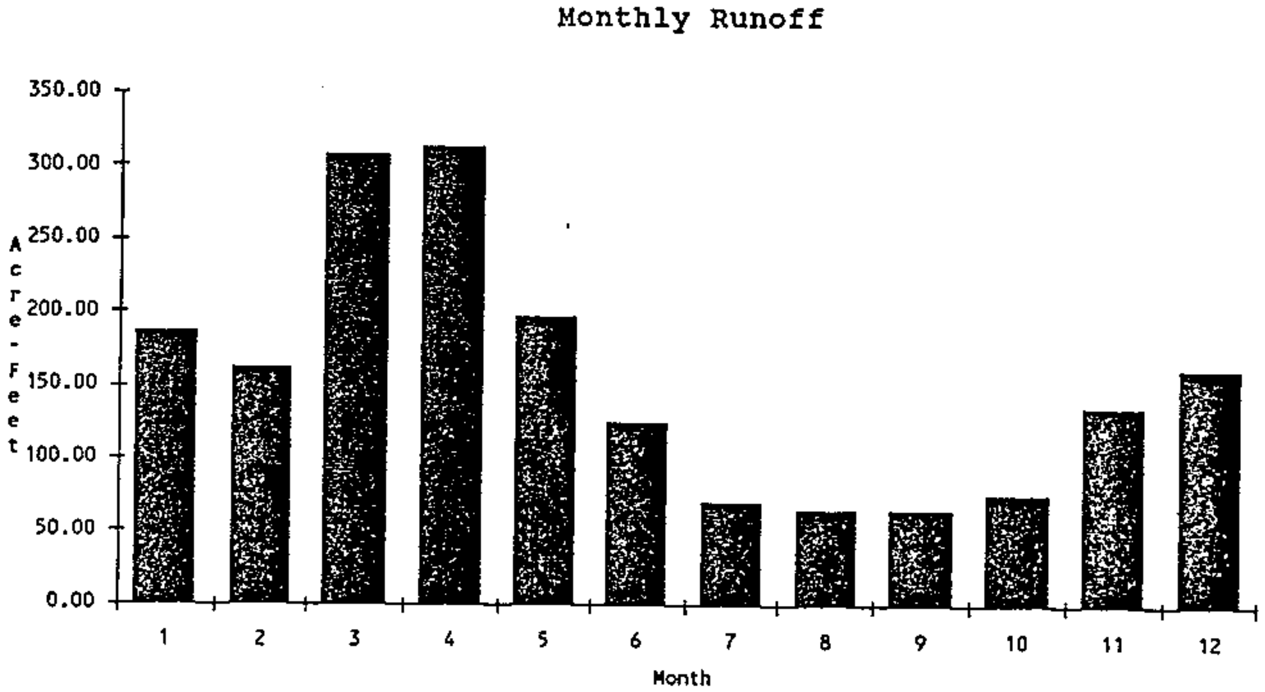
Mean Annual Flowrate (c.f.s.) = 2.60

**************** **************** *************** ****************

Note: These values were computed based on mean monthly runoff from a thirty year interval (1931-1960) in the Lower CT River Basin. These values represent estimates of average conditions. Actual runoff will depend on actual precipitation, antecedent precipitation, and rainfall-runoff relationships of a particular landscape. (Source Water Resource Inventory of Connecticut Part 10 - U .S.G.S.)

CHART3.XLC

Figure 3



I.C. Streamflow Monitoring

The inlets were sampled three times by Ecosystem Consulting Service, Inc. during this study: June 28, 1990, August 17, 1991 and between March 14 and April 18, 1991. In addition, five sets of storm samples were taken by residents involved in the local resident sampling program. These samples were taken on July 31, August 6, August 25 and September 15 of 1990 and March 4 of 1991. On all but the sampling between March 14 and April 18, 1991, only the 3 principal inlets (1, 4, 5) were sampled. This represents 8 sampling dates for these three streams. The last sampling visit occurring on March 14 and April 18 was interrupted due to vehicle failure. During the two visits, four additional sites were sampled. The location of the sampling sites is shown in Figure 2.

Discharge

The discharge in Liters/sec was estimated using a Pigmy Gurley meter to measure correct velocity. Measurements were taken during each of the 3 E.C.S., Inc. field visits. The estimates as presented in Table 2 ranged from a low of 1 L/s to a high of 20 L/s. The means ranged between 10 and 23 L/s for inlets 1, 3, and 5. These values are low and represent the small drainage areas. The sampling dates did not occur during storms so these values represent base flow condition.

Temperature

The stream water temperature was measured on the same dates the discharge was estimated. Table 3 presents the temperature data taken during the study. Inlet #4 appears to have the lowest inflow water temperature, while inlet 1 had the highest. The large wetland upstream of the sampling point in inlet 1 may warm the water by slowing down its travel time and increasing solar radiation contact. Inlet #4 may be cooler because of the lack of any large wetland areas.

The range of temperatures is normal and is characteristic of healthy stream systems.

Phosphorus

Table 4 presents total phosphorus data from the tributaries. The values ranged from a low of 6 to a high of 370. The mean values for inlets 1, 4, and 5 ranged from 38 to 72. This indicates that no serious external load problem exists. Basin 4 had the highest values and should be investigated further. The concentrations of the storm samples (7-31, 8-06, 9-15) are the highest and indicate runoff effects such as first flush and streambed scour. Storm runoff in summer months also tends to drain only impervious surface areas since the vegetation cover absorbs the rainfall from other areas (woods, wetland, etc.). This increases the concentration of phosphorus because of a lack of dilution from areas where the loading is not as high.

ROARING BROOK INLET CHEMISTRY

Discharge (L/s)

Date

Site	06-28	07-31	08-06	08-17	03-4	03-14	04-18	Mean
OUTLET	---	---	---	---	---	---	---	
INLETS								
1	1	---	---	12	---	17	---	10
2	---	---	---	---	---	1	---	1
3	---	---	---	---	---	---	10	10
4	3	---	---	20	---	---	12	12
5	4	---	---	18	---	---	15	12
6	---	---	---	---	---	---	5	5
7	---	---	---	---	---	---	3	3

Table 3

ROARING BROOK INLET CHEMISTRY

Temperature C

Date

Site	06-28	07-31	08-06	08-17	03-4	03-14	04-18	Mean
OUTLET	23.5	---	---	---	---	---	---	
INLETS								
1	20.5	---	---	18.5	---	-2.8	---	
2	---	---	---	---	---	0	---	
3	---	---	---	---	---	---	9	
4	16.0	---	---	16.0	---	---	9	
5	17.9	---	---	17.5	---	---	9.5	
6	---	---	---	---	---	---	8	
7	---	---	---	---	---	---	10	

Table 4

ROARING BROOK INLET CHEMISTRY

Total Phosphorus (ppb)

	Date		1990			
Site	06-28	07-31	08-06	08-17	08-25	09-15
OUTLET	7	---	---	---	---	---
INLETS						
1	23	46	87	20	34	63
2	---	---	---	---	---	---
3	---	---	---	---	---	---
4	11	113	370	12	13	25
5	14	111	57	20	27	46
6	---	---	---	---	---	---
7	---	---	---	---	---	---

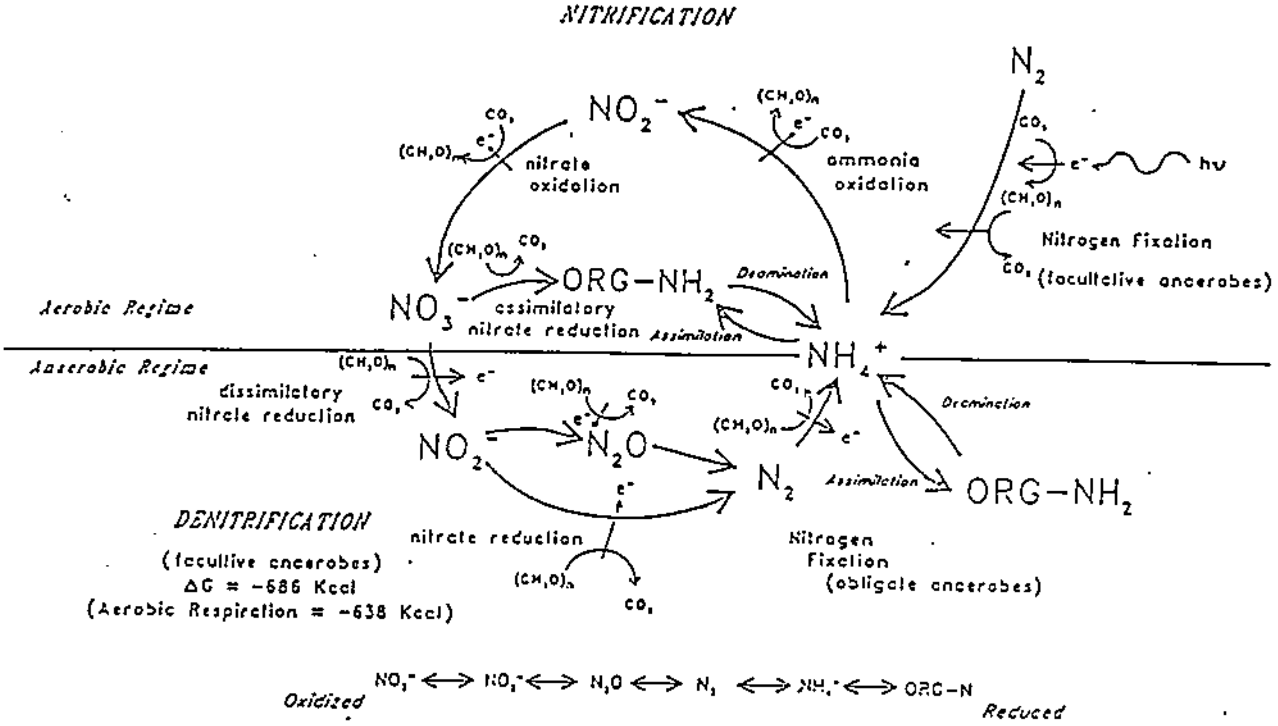
	Date	1991			
Site	03-4	03-14	04-18		Mean
OUTLET	---	---	---	....	7
INLETS					
1	20	8	---	....	38
2	---	**6**	---	....	6
3	---	---	7	....	7
4	22	---	10	....	72
5	21	---	27	....	40
6	---	---	11	....	11
7	---	---	14	....	14

☐=Maximum Value **6** = Minimum Value

Nitrogen Cycle

Ammonia nitrogen is generated in decomposition processes (deamination of amino acids). Under aerobic (oxygen rich) conditions, ammonia will not accumulate because it is oxidized by naturally occurring bacteria (nitrification to nitrite, then nitrite). We have included a figure (Figure 4) which illustrates the important features of the nitrogen cycle in aquatic ecosystems. When waters are devoid of oxygen, ammonia accumulates (it can't be oxidized by the aforementioned bacteria) and nitrate serves as an "alternate" to oxygen in decomposition (a very important process called denitrification).

FIGURE 4



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Ammonia

The tributary concentrations presented in Table 5 ranged from <10 to 81 ppb, with only 3 values over 20 ppb. All observations can easily be accounted for by natural processes -- not contamination. Wetlands tend to have anoxic, waterlogged soils; hence ammonia is generated. Wetland drainage is typically high in ammonia and dissolved organic nitrogenous compounds. In streams between watershed wetlands and the lake, ammonia is nitrified to nitrate. This is likely responsible for the nitrate concentrations which <u>appear</u> to be elevated.

Nitrate/Nitrite

The nitrate/nitrite concentrations are presented in Table 6. They are all within the range (<20 to 380 ppb) expected for this type of ecosystem. They do not indicate a problematic condition.

Table 5

ROARING BROOK INLET CHEMISTRY

Ammonia

Site	Date 06-28	07-31	1990 08-06	08-17	08-25	09-15
OUTLET	<10	---	---	---	---	---
INLETS						
1	<10	18	<10	<10	<10	<10
2	---	---	---	---	---	---
3	---	---	---	---	---	---
4	<10	<10	80	<10	<10	<10
5	<10	77	<10	<10	<10	<10
6	---	---	---	---	---	---
7	---	---	---	---	---	---

Site	Date 03-4	1991 03-14	04-18		Mean
OUTLET	---	---	---	....	<10
INLETS					
1	<20	<20	---	....	<20
2	---	<20	---	....	<20
3	---	---	<10	....	<10
4	<20	---	<10	....	<18
5	<20	---	16	....	<21
6	---	---	<10	....	<10
7	---	---	☐ 81	....	81

☐=Maximum Value **<10** = Minimum Value

Table 6

ROARING BROOK INLET CHEMISTRY

Nitrate + Nitrite

	Date		1990			
Site	06-28	07-31	08-06	08-17	08-25	09-15
OUTLET	<50	---	---	---	---	---
INLETS						
1	170	$\boxed{380}$	130	<50	<50	160
2	---	---	---	---	---	---
3	---	---	---	---	---	---
4	110	330	80	<50	<50	<50
5	<50	300	50	<50	<50	208
6	---	---	---	---	---	---
7	---	---	---	---	---	---

	Date	1991			
Site	03-4	03-14	04-18		Mean
OUTLET	---	---	---	....	<50
INLETS					
1	70	**<20**	---	....	<129
2	---	130	---	....	130
3	---	---	<20	....	<20
4	70	---	36	....	<97
5	70	---	**<20**	....	100
6	---	---	290	....	290
7	---	---	160	....	160

☐=Maximum Value **<20** = Minimum Value

pH and Conductivity

Tables 7 and 8 present pH and specific conductance data. Conductivity is indicative of a "moderately soft water lake" (expected from wetland observations). The values ranged from a low of 42 to a high of 260. Generally, inlet 5 had the highest values and inlet 4 had the lowest. The pH of inflow was consistently slightly acid (pH 7 = neutral). The values ranged from a low of 5.5 for inlet 2 on 3-14-91 to a high of 6.8. Generally, the values ranged between 6.0 and 6.8. Again, this is typical of wetland drainage. The in-lake pH readings were slightly higher. This is caused by photosynthesis, which removes carbon dioxide ("fixing" it in organic matter), and hence shifting the carbonate buffering system slightly up the pH scale. Again, this observation is typical of this type of lake ecosytem. Actually, it is encouraging that pH/conductivity is not lower (as in true "bog" ecosystems).

Table 7

ROARING BROOK INLET CHEMISTRY

Conductivity

Site	Date 06-28	1990 07-31	 08-06	 08-17	 08-25	 09-15
OUTLET	134	---	---	---	---	---
INLETS						
1	84	70	**42**	72	57	62
2	---	---	---	---	---	---
3	---	---	---	---	---	---
4	69	52	106	53	51	54
5	135	101	83	118	102	123
6	---	---	---	---	---	---
7	---	---	---	---	---	---

Site	Date 03-4	1991 03-14	 04-18	Mean
OUTLET	---	---	---	 134
INLETS				
1	75	101	---	 70
2	---	75	---	 75
3	---	---	**42**	 42
4	49	---	50	 60
5	95	---	105	 95
6	---	---	207	 207
7	---	---	$\boxed{260}$	 260

☐=Maximum Value **42** = Minimum Value

Table 8

ROARING BROOK INLET CHEMISTRY

pH

	Date		1990			
Site	06-28	07-31	08-06	08-17	08-25	09-15
OUTLET	7.2	---	---	---	---	---
INLETS						
1	6.8	6.6	6.4	6.5	6.6	☐ 6.9
2	---	---	---	---	---	---
3	---	---	---	---	---	---
4	6.6	6.4	6.4	6.1	6.7	6.7
5	6.6	6.6	6.3	6.2	6.6	6.7
6	---	---	---	---	---	---
7	---	---	---	---	---	---

	Date	1991			
Site	03-4	03-14	04-18		Mean
OUTLET	---	---	---	....	7.2
INLETS					
1	6.1	6.1	---	....	6.5
2	---	**5.5**	---	....	5.5
3	---	---	6.8	....	6.8
4	5.8	---	6.5	....	6.4
5	6.0	---	6.5	....	6.4
6	---	---	6.8	....	6.8
7	---	---	6.7	....	6.7

☐=Maximum Value **5.5** = Minimum Value

Fecal Coliform Bacteria

Table 9 presents fecal coliform bacteria values collected from the inlet stations. The values ranged from a low of less than 10 colonies per 100 mls to 320 colonies per 100 mls. These preliminary tests suggest that some localized areas should be examined further. These values are not excessive and are of no cause for alarm. The data indicate that no serious contamination problem exists.

Table 9

ROARING BROOK INLET CHEMISTRY

Fecal Coliform Bacteria (/100)

Site	Date 06-28	07-31	08-06	08-17	03-4	03-14	04-18	Mean
OUTLET	625	---	---	---	---	---	---	625
INLETS								
1	25	---	---	100	---	<10	---	45
2	---	---	---	---	---	<10	---	<10
3	---	---	---	---	---	---	320	320
4	25	---	---	100	---	---	40	55
5	175	---	---	<50	---	---	<10	78
6	---	---	---	---	---	---	10	10
7	---	---	---	---	---	---	<10	<10

The results of the stream inflow monitoring indicate that no serious watershed loading problem exists for Roaring Brook Lake. The major nutrients, Phosphorus and Nitrogen, were found to be in low concentrations in the inflow streams. Storms did contain higher values, but even these were not excessive. One value of 320 TP was measured for inlet #4 on August 6, 1990, while in July, 380 ppb of nitrate-nitrite was measured for inlet 1. These summer runoff events may be draining mostly impervious surface areas and represent loading from the residential areas around the lake. The nutrient content of these streams should be monitored during storm events on a regular basis to determine if there are specific areas in need of watershed management practices.

The inflow chemistry also appears to be influenced by wetlands in the basin. The pH was consistently below 7 (neutral) and baseflow conductivity was generally below 100 ohs/cm. Some of the higher conductivity levels seen in inlets #5, 6, and 7 may be due to road runoff from the Taconic State Parkway. There doesn't seem to be associated nutrient loading due to the highway, however. Stormwater runoff conveyance from the highway to the lake should be mapped so that inlet sampling can be used to monitor its contribution to the lake of nutrients and other possible contaminants.

I.D. Nutrient Budget

The phosphorus loading to Roaring Brook Lake was estimated using two different approaches; the Spring Phosphorus Model and the Land-use Model. Both are explained and presented with calculations. Prior to this is a short introduction to nutrient budgets.

A nutrient budget is much like a household budget. Both itemize income and outgo, and both tell you what's left. The concept is based on the principle that material (and money) is neither created nor destroyed. Thus, the amount of a nutrient in a lake depends upon the balance between summed inputs and outputs (the "input-output budget model").

Input-output budgets for total phosphorus, total nitrogen, dissolved and particulate organic matter, and several other substances are useful to a lake manager. The first objective of nutrient budgeting is to itemize and estimate the relative importance of nutrient sources (inputs). An important distinction exists between external (watershed) sources and internal (in-lake release) sources. External nutrient sources are susceptible to more direct and cost-effective management than internal sources. The second objective of nutrient budgeting is to estimate the balance of nutrient residuals in the lake. This aspect of nutrient budgets is a major new chapter in limnology (the study of lakes).

Basic research over the last 20 to 30 years in the theory and practice of estimating lake nutrient budgets and their effects has created a series of useful "models" for important nutrients. The models are detailed mathematical expressions which estimate a critical piece of very difficult to obtain information from several pieces of much easier to obtain information. Essentially, the models use one or more very well tested correlations between what is known and what needs to be known about a lake. Thus, a lake manager can "plug into the model" what he knows about his specific lake, "run the model", and obtain the benefit of computations based on intensive research done elsewhere that he could never hope to duplicate on his own lake. Models have the potential to mislead, of course, and a responsible lake manager verifies model results with research on his own lake. Phosphorus models based on lake characteristics and land-use practices, models based on **synoptic field sampling**, unit hydrograph models, septic performance models, etc. are efficient applications of basic science to practical problems, and they give a skillful lake manager predictive and diagnostic powers.

Nutrient Budgets: Spring Phosphorus Model

Several models have been derived which relate the concentration of phosphorus in a lake in spring (ice-out) to "**phosphorus tolerance**" of a lake, and "**allowable phosphorus**" inputs. In addition to a determination of the concentration of total phosphorus at ice-out, these models use readily available inforjmation about lakes such as mean (average) depth, lake surface area, drainage basin area, etc.

The Dillon-Rigler Model, the most popular type of spring phosphorus model, uses only the spring phosphorus concentration, the annual water budget, and some general dimensions of the lake. The model serves several applications. First, it provides an estimate of the total annual phosphorus load on a specific lake. Second, this estimate can be compared to annual phosphorus loads at other lakes to establish a criterion for watershed performance and potential management. Third, the model can be "run backwards" to find the concentration of spring phosphorus which must be achieved to reach a particular management goal. Finally, the estimate of phosphorus loading from the model can be compared to actual input measurements to verify that sources have been found and controlled.

The chief weakness of the Dillon-Rigler Model is its total focus on watershed sources. Later in the growing season when evapotranspiration by the terrestrial plant community is at a maximum and watershed discharge to the lake is at a minimum, the concentration of phosphorus in lakes begins to be influenced by in-lake factors such as recycling from the sediments. These complications are likely in more shallow lakes, lakes with anoxic hypolimnia, and lakes susceptible to mixing by wind. Recent research on the effects and modelling of internal events such as hypolimnetic anoxia and mixing offer some promise for future management of lake nutrient recycling.

NUTRIENT BUDGETS

Three useful models to estimate the nutrient status of lake ecosystems based on external (watershed) inputs. They use an annual time scale and tend to be insensitive to seasonal effects. These models focus on external nutrient sources, hence do not work for internal nutrient sources.

a: $$TP = \frac{L\,(1-Rp)}{\bar{\bar{z}}\,\rho};\quad Rp = \frac{13.2}{13.2} + qs$$

TP = total phosphate ppb

L = phos. load per area

$\bar{\bar{z}}$ = mean depth

ρ = flushing rate

qs = annual water load relative to surface area

Rp = phos. retention fraction

a. Kirchner and Dillon Model.

A spring phosphorus model derived by W. B. Kirchner and P. J. Dillon, this is a variant of the "Dillon-Rigler" type model. The model predicts phosphorus content of a lake based upon hydrology (flushing rate and water load) and dimensions of the lake such as area and mean depth. The model can be manipulated algebraically for a number of uses, including a comparison of computed and observed phosphorus concentrations to detect internal phosphorus loading by re-cycling in the lake.

Table 10 presents the results of three empirical total phosphorus (TP) load models based on spring (mixing conditions) TP concentrations. During this study, a spring TP concentration was not determined. An estimate of 12 ppb was used based on the June 28, 1990 in-lake concentration of 10 ppb. The actual spring concentration of TP should be determined as part of routine field monitoring of Roaring Brook Lake. The models indicate an existing external annual watershed nutrient loading of between 81.2 and 98.3 kg of Phosphorus per year (mean = 90.69 kg P/yr). Increasing the estimated spring TP concentration to 20 ppb to be conservative results in a prediction of 150 kg P/yr. Dividing by watershed land area (954 acres) results in an average of 0.095 kg per acre or a watershed-wide export coefficient of 23 mg per square meter per year for 12 ppb spring TP and 0.16 kg per acre and 39 mg per square meter per year for 20 ppb spring TP. These values are well below a permissible loading level for a lake of this type.

Table 10

PREDICTIVE LAKE EUTROPHICATION MODELS

ROARING BOOK LAKE 1990

Morphometry (Lake and Watershed Statistics)
data from ECOSCIENCE REPORT 1988
****

Total Precipitation =	47.20 inches	ASSUMED
Effective Precipitation =	23.60 inches	ASSUMED
Average Evaporation =	37.50 inches	ASSUMED
Lake Surface Area =	110 acres 445155 square meters	DATA
Littoral Area = (<15.0 feet)	102 acres 412780 square meters	
Profundal Area (Too deep for weeds	8 acres 32375 square meters	
Watershed Area (Excluding Lake)	954 acres 3859086 square meters	
Lake/Watershed Area	10.34 %	
Lake Volume	877 acre-ft 1081762 cubic meters	
Mean Depth	8.0 feet 2 meters	
Maximum Depth	16 feet 5 meters	
Mean Depth/Maximum Depth	0.50 Ratio	
Shoreline	14000 feet 4268 meters	
Shoreline Development Index	1.81 Ratio	
Residence Time	0.47 years	
Inflow Rate	1875 acre-ft / year 2313285 cubic meters / year	
Outflow Rate	1964 acre-ft / year 2422962 cubic meters / year	
Gross PPT on Lake	433 acre-ft / year 533686 cubic meters / year	
Net PPT on Lake	89 acre-ft / year 109677 cubic meters / year	

```
ROARING BOOK LAKE                                     1990

Assumed Values:

 Symbol    Value      Units        Meaning or Definition

P Budge        kg/yr               Total P Input to Lake
     TP     12 mgP/m-3             Spring Total Phosphorus Conc.
      L        mg P/m-2/yr         Aerial Annual Phosphorus Load
    -z-   2.43 m                   Mean Depth
      F   2.14 times/year          Flushing Rate
      S   0.24 non-dim fraction    TP Leaving Lake/ TP Entering Lake
     qs   5.20 m-3/yr/m-2          Aerial Water Load (-z- * F)
      v   0.59 m/year              Apparent Settling Velocity (-z- * S)
      R   0.65 non-dim fraction    Retention Coefficient (estimated)
     Rp   0.72 non-dim fraction    Retention Coefficient (Water Load)


*************************
Kirchner and Dillon 1975
*************************

Prediction of TP from L,R,-z-, and F:

     TP = L (1-R) / -z- (F) ... where R=TPin/TPout/ TPin

     Predicted T                   mg P / cubic meter

Prediction of L from TP,-z-,F, and Rp:

     L = TP (-z-) (F) / (1-Rp) ... where TP is Observed
                Observed TP=              12 mg P/cubic meter

      Predicted             220.78 mg P / square meter / year
   Predicted TP Load                 98.28 kg/year
******* ******** **************** ******** ******** ******** ********
```

```
ROARING BOOK LAKE                                        1990
******* ******** **************** ******** ******** ******** ********
Vollenweider 1975
*************************

Prediction of TP from L, -z-, F, and S:

     TP = L / -z- (S+F)               where S= 10/-z-
                                            S= 4.114025

     Predicted T                      mg P/ cubic meter

Prediction of L from TP, -z-, F, and S:

    L= TP * (-z-(S+F))

     Predicted L               182.38 mg P/square meter / year
     Predicted TP Load=                  81.19 kg/year

*******************************************
Chapra 1975
*************************

Prediction of TP from L, R, -z-, and F:

     TP = L(1-R) / -z-(F) ... where R=v/qs+v and v=12.4
                                                    R=      0.70
   Predicted TP=

Prediction of L from TP, R, -z-, and S:

     L = (TP)(-z-)(F) / (1-R)
                 Observed TP=               12 mg P/ cubic meter

     Predicted L               208.06 mg P/square meter/year
     Predicted TP Load=                  92.62 kg/year

************************

SUMMARY OF EMPIRICAL MODEL RESULTS

Prediction Of: TP from Estimated L          Load from Observed TP
                mg P / cubic meter              kg/year

K&D 1975
                                                       98.28

V 1975
                                                       81.19

Chapra 1975
                                                       92.62
-------------------------------------------------------------------
TP Predicted from Samp Conc.....(12 ppb)  Avg =          [illegible]
                1990
```

Nutrient Budgets: Land-Use Models

Efforts to reduce lake eutrophication by managing watersheds are more effective when contributions of nutrients from specific land-uses are known. Figure 23 illustrates a model which predicts export of phosphorus from a unit surface area of watershed in either urban, agricultural, or woodland use. When verified in the field by comparing predicted to observed phosphorus concentrations, this approach establishes the relative importance of various parts of the watershed for control.

Another method for measuring the relative importance of various parts of the watershed is a watershed model which estimates the phosphorus contribution from non-point sources. The model is described in detail in the Windham Regional Planning Agency Report, Lake Management Handbook: A Guide to Quantifying Phosphorus Inputs to Lakes.

b: $$P = \frac{(Q + 1.2)}{Q + 12}(170U + 54A + 10W)/D$$

P = phos. conc. ppb

Q = meters of water per year of load relative to surface area

D = water export from entire watershed in meters per year

U,A,W = fractions of watershed in urban, agricultural and woodland areas

b. Connecticut Agricultural Experiment Station Model.

A land-use model derived for Connecticut lakes by W. A. Norvel, C. R. Frink, and D. E. Hill. The model predicts the concentration of phosphorus from watershed use, i.e. the amount in urban, agricultural, or woodland classifications.

An estimate of the phosphorus loading from the whole basin was made using land-use fractions from the Ecoscience Report of 1988. The phosphorus export coefficients were taken from Frink and Norvell, 1984. The results of this calculation are presented in Table 11 and illustrated in Figure 5. The model indicates an existing external load of approximately 112 kg yr^{-1}. The empirical phosphorus model estimated 90 kg yr^{-1}. These two independent approaches are in close agreement. It is likely that the spring TP concentration is somewhat higher. This would bring the two estimates into very close agreement. For instance, if a spring TP of 15 is used, the empirical model would predict a loading of 113 kg yr^{-1}.

Table 11

ROARING BROOK WATERSHED LOADING

LAND USE METHOD

Subbasin Land Use Fractions (ha)

Land Use	A	B	C	D	E	F	TOTAL
Urban	7.6	15.4	6.8	5.7	6.7	3.2	45.4
Agriculture	0	0	0	0	0	0	0
Wooded	44.6	54.6	92.8	14.9	45.9	96.8	349.6
	52.2	70	99.6	20.6	52.6	100	395

P Export Coefficients

	kg/ha	lb/Ac
Urban	1.70	1.52
Agriculture	0.54	0.48
Wooded	0.10	0.09

Subbasin Calculated P Export (kg)

Land Use	A	B	C	D	E	F	TOTAL
Urban	12.9	26.2	11.6	9.7	11.4	5.4	77.2
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wooded	4.5	5.5	9.3	1.5	4.6	9.7	35.0
TOTAL	17.4	31.6	20.8	11.2	16.0	15.1	112.1

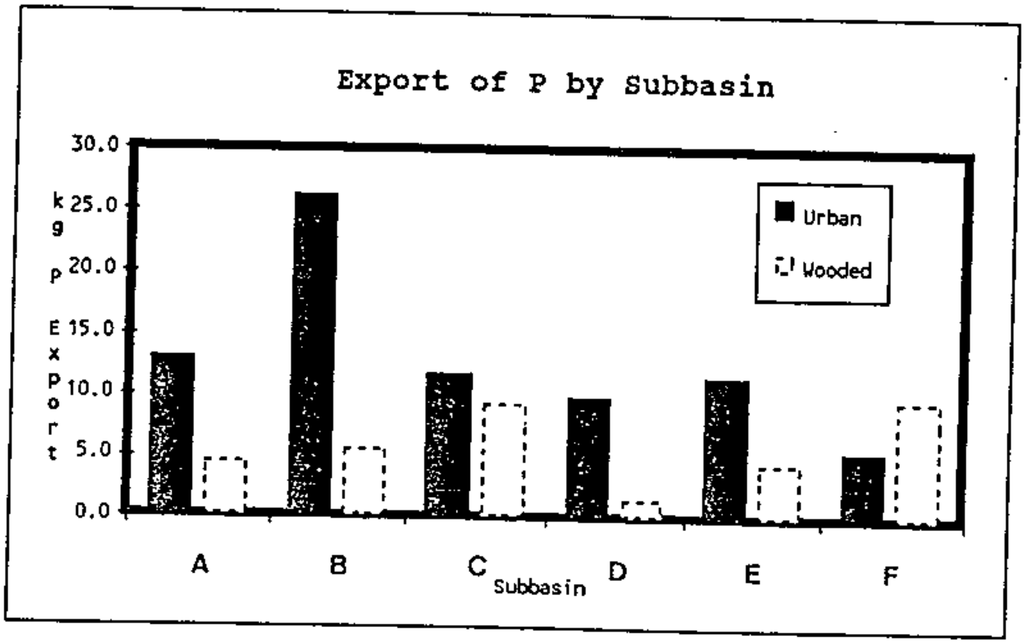


Figure 5

II. In-lake Ecosystem Structure and Function

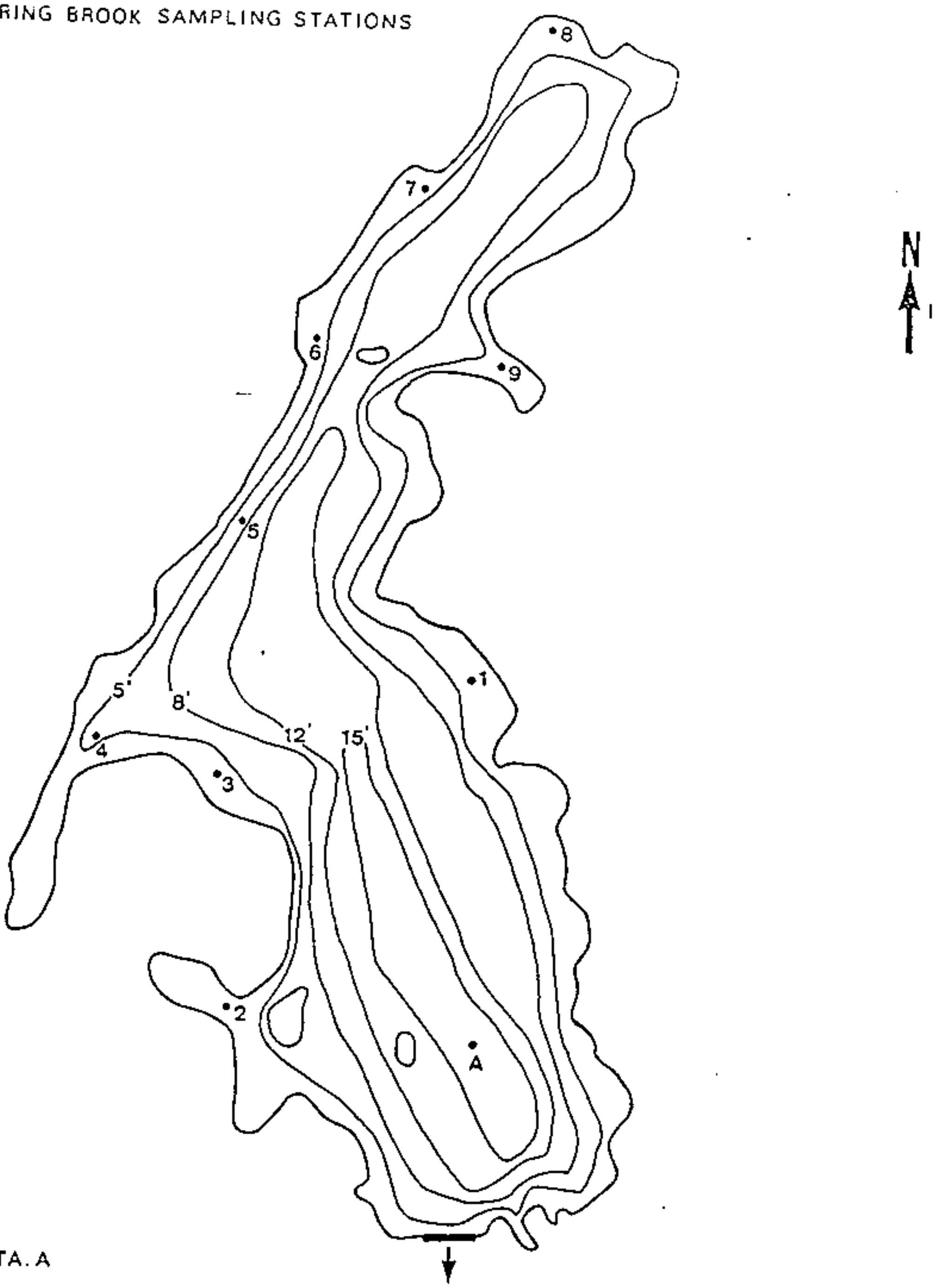
A. Bathymetry and Morphometry

The bathymetry of Roaring Brook Lake is presented in Figure 6 (redrawn from Ecoscience Report, 1988). The fundamental characteristics on any lake ecosystem are its specific areas and volumes at each depth increment relative to the nature of stratification, and the hydrology of the system. Table 12 presents the details of areas and volumes which occur at each depth increment in Roaring Brook Lake. The mean depth is 7.9 feet (2.4 meters) while the maximum depth is 16 feet (4.9 meters). The volume is 877 acre-feet. The morphometry and monthly hydrology is integrated in Table 13 to determine average monthly flushing rates.

The relationship between surface area and depth is presented in Figure 7. At each depth increment less of the surface area occurs as sediment. This is also demonstrated by the sediment contact area graph presented in Figure 8. This graph plots the % of surface area that exists within each depth interval. The general trend is declining amounts of exposed sediments in the deeper water.

FIGURE

LOCATION OF ROARING BROOK SAMPLING STATIONS



BACKGROUND: STA. A

SURFACE GRABS: STAS. 1-9

SCALE: 0' 608'

Table 12

LAKE BASIN MORPHOMETRY : ROARING BROOK LAKE

Surface Areas Digitized by ECS, Inc., 1990
from Ecoscience Bathymetry Map

	Feet
Max depth	16.0
Mean Depth	7.9

DEPTH (feet)	SURFACE AREA AT DEPTH (acres)	SURFACE AREA OF STRATUM (acres)	SURFACE AREA AT DEPTH (percent)	SURFACE AREA OF STRATUM (percent)
0	110.49	32.05	100.00	29.01
5	78.44	23.67	70.99	21.42
8	54.77	29.07	49.57	26.31
12	25.70	17.57	23.26	15.90
15	8.13	8.13	7.36	7.36
TOTAL		110.49		100.00

DEPTH (feet)	VOLUME BELOW DEPTH (acre-ft)	VOLUME OF STRATUM (acre-ft)	VOLUME BELOW DEPTH (percent)	VOLUME OF STRATUM (percent)
0	877.11	470.04	100.00	53.59
5	407.07	198.76	46.41	22.66
8	208.31	157.32	23.75	17.94
12	50.99	48.28	5.81	5.50
15	2.710	2.71	0.31	0.31
TOTAL		877.11		100.00

Table 13

Estimated Montly Flushing of Lake Volume

ROARING BROOK LAKE

Lake Volume... 877 Acre-Feet

MONTH	Mean Monthly Runoff acre-ft/month	Predicted Flushing % Vol.
January	186.91	21.31
February	162.12	18.49
March	307.11	35.02
April	312.51	35.63
May	196.92	22.45
June	124.15	14.16
July	69.80	7.96
August	64.21	7.32
September	64.21	7.32
October	75.20	8.57
November	135.69	15.47
December	161.19	18.38
	1860.01	212.09

Annual Flushing Rate 2.12

Figure 7

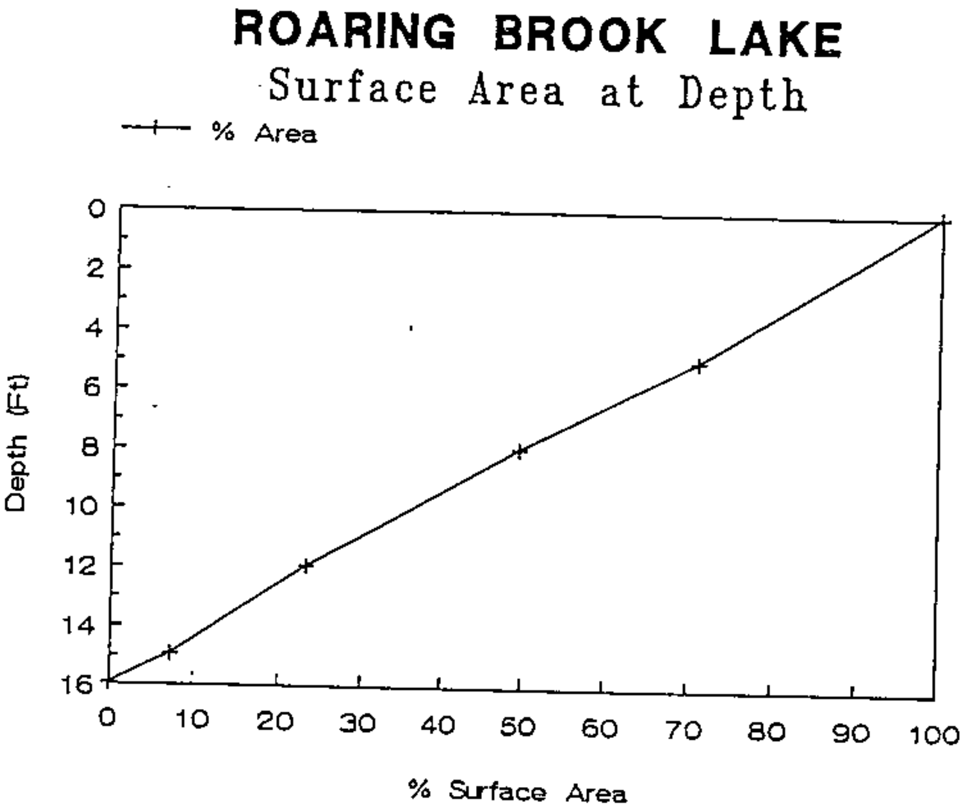
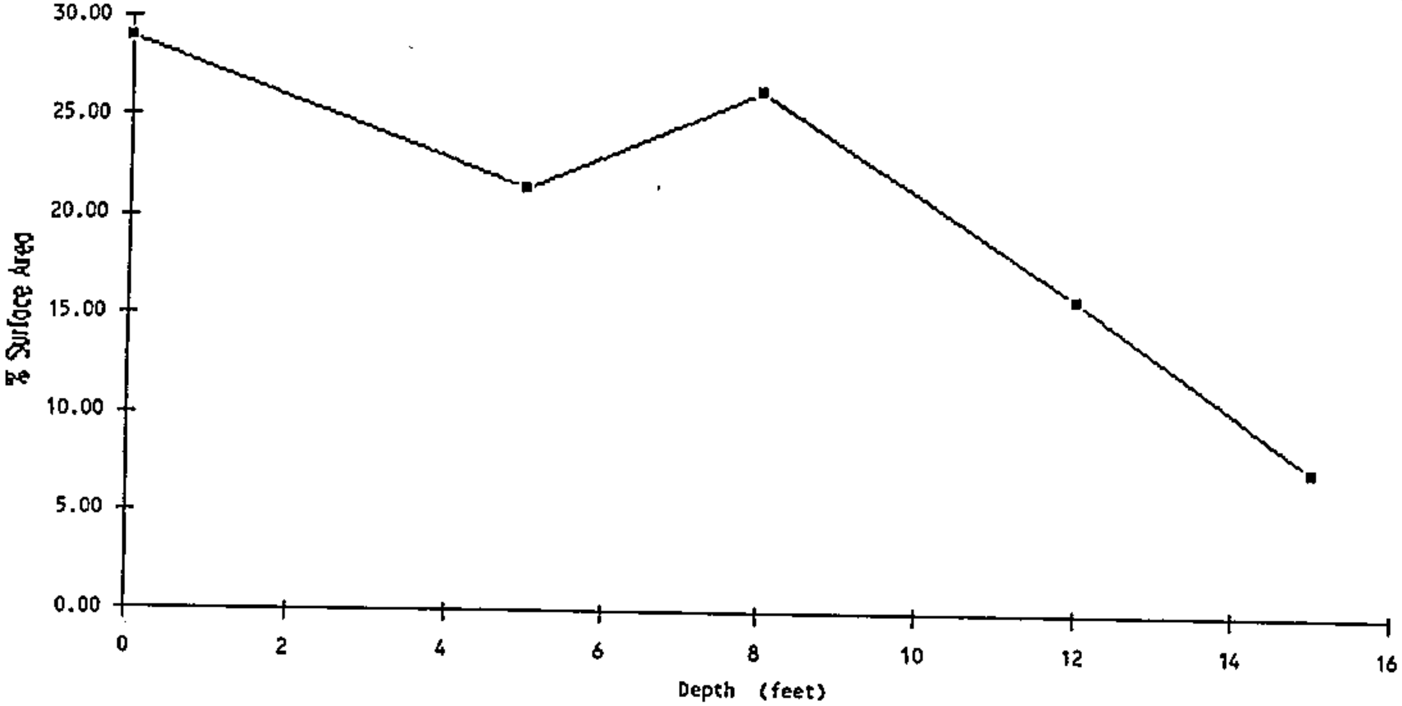

ROARING BROOK LAKE
Surface Area at Depth
% Area
Depth (Ft)
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70
80
90
100
% Surface Area

Figure 8.

Sediment Contact Area



"In the lake" - Physical/Chemical Events

As a lake warms in spring, it absorbs heat from the "top down". Lakes are very efficient solar collectors. Wind energy mixes the water (also from the top down). Warm water is less dense ("lighter", than cold water. Furthermore, the density difference per degree Centigrade becomes larger as waters become warmer. As surface water collects heat in the spring it tends to float on colder, deeper water. Eventually, the density differences caused by temperature difference overcome the ability of wind to keep the lake mixed. Hence, thermal stratification develops and the bottom water stagnates (becomes isolated from the atmosphere and oxygen exchange). This "stratification-stagnation" has profound effects on water quality, habitat, and nutrient cycling in the lake.

TEMP = the observed temperature at each 1 meter depth increment (in degrees C).

DO = the observed oxygen content in milligrams per liter (mg/l) which is equivalent to parts per million (ppm). Generally, fish require more than about 3-4 mg/liter DO (temperature dependent) while most of the small animals that eat algae (zooplankton) require more than 1 mg/liter.

% SAT = This compares the oxygen concentration at the observed temperature with the concentration expected at that temperature if the water were at equilibrium with atmospheric oxygen content. When % SAT exceeds 100, photosynthesis is producing excess oxygen. When less than 100%, respiration is consuming more oxygen than is being replenished (just as we consume oxygen and exhale carbon dioxide).

RTRM = "relative thermal resistance to mixing". This is an index that quantifies the intensity of density differences due to different temperatures of adjacent water strata. The higher the RTRM, the greater the density difference, hence the more difficult it is for wind mixing to occur. Generally, RTRM 30 identifies the boundary conditions of the mid-depth "metalimnion" while RTRM maximum identifies the location (depth) and intensity of the thermocline. In general, a "strongly stratified lake" will exhibit an RTRM max > 80.

SECCHI DEPTH = depth to which a 20 cm (8 inch) diameter white disk can be seen by the human eye. This measurement is a very simple informative parameter. Typically, aquatic macrophytes ("rooted weeds") will be limited to the depth of Secchi transparency, and the "compensation depth" (depth at which photosynthetic oxygen production offsets respiratory oxygen consumption) typically equals about 1.7-1.9 times the Secchi depth (aproximately the 1% level of incident "photosynthetically active radiation" or "PAR"). Although these features relative to Secchi disk depth do vary somewhat between lakes, it is a very informative parameter.

ANOXIC BOUNDARY = for convenience, the depth at which oxygen concentration drops below 1 mg/liter is interpolated by the computer program, and is listed on the printout.

The individual sampling depth profiles taken during the study (June 28, 1990 and August 17, 1990) are illustrated in Figures 9 and 10. Each of the two profiles is illustrated diagrammatically in Figure 11. Each of these two profiles was taken at the deep water station ("A" on Figure 2).

The first profile (taken on June 28, 1990) demonstrates that there was significant thermal stratification, with a thermocline at approximately 4m. This is indicated by a peak in the RTRM number (79). The depths where the RTRM is zero indicates that there is no density difference between these depths so the water is free to mix.

Oxygen loss occurred below 4 meters. At 5 meters the oxygen concentration was 1.2 mg/l. This area covers about 8 acres (7% of lake area; ca. 0.3% of the lake volume). Oxygen production occurred in water up to 4 meters deep; at 4 meters the oxygen saturation was slightly less than 100%. The water transparency as estimated by the Secchi depth was 4.6 meters (15.1 ft). The depth of oxygen production is a reflection of the depth of light penetration. Enough light was getting to algae as deep as 4 meters for active photosynthesis to occur. This maintains highly oxygenated water. The depth of the thermocline is also a reflection of the depth of light penetration. Since the light is what is warming the water, below the point where light no longer reaches the water remains cool. This forms the density difference and hence the thermocline.

Figure 9

LAKE ROARING BROOK
June 28, 1990
STATION A

SECCHI DEPTH 4.6 METERS
ANOXIC BOUNDARY 0 METERS

DEPTH METERS	TEMP °C	DO mg/L	%SAT	RTRM
0.0	23.0	9.0	107	0
1.0	23.0	9.1	109	0
2.0	23.0	9.0	107	0
3.0	21.0	9.4	108	56
4.0	17.8	9.0	98	79
5.0	15.5	1.2	12	48

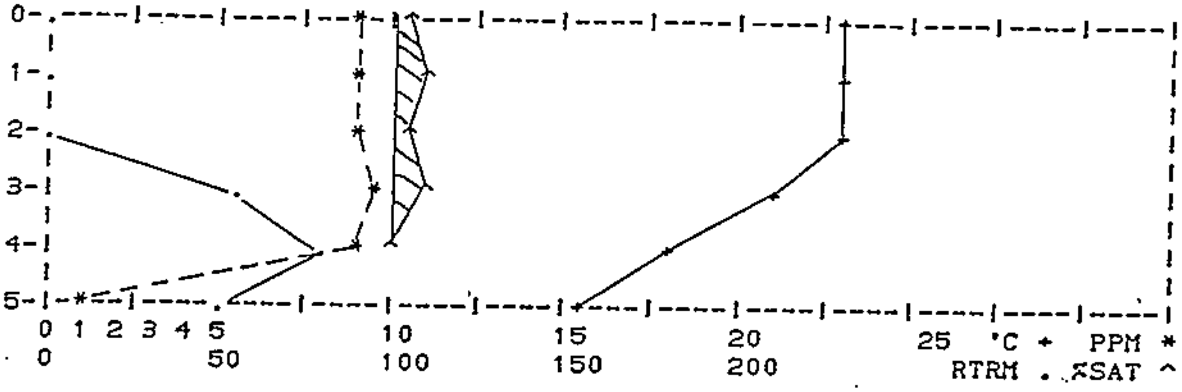
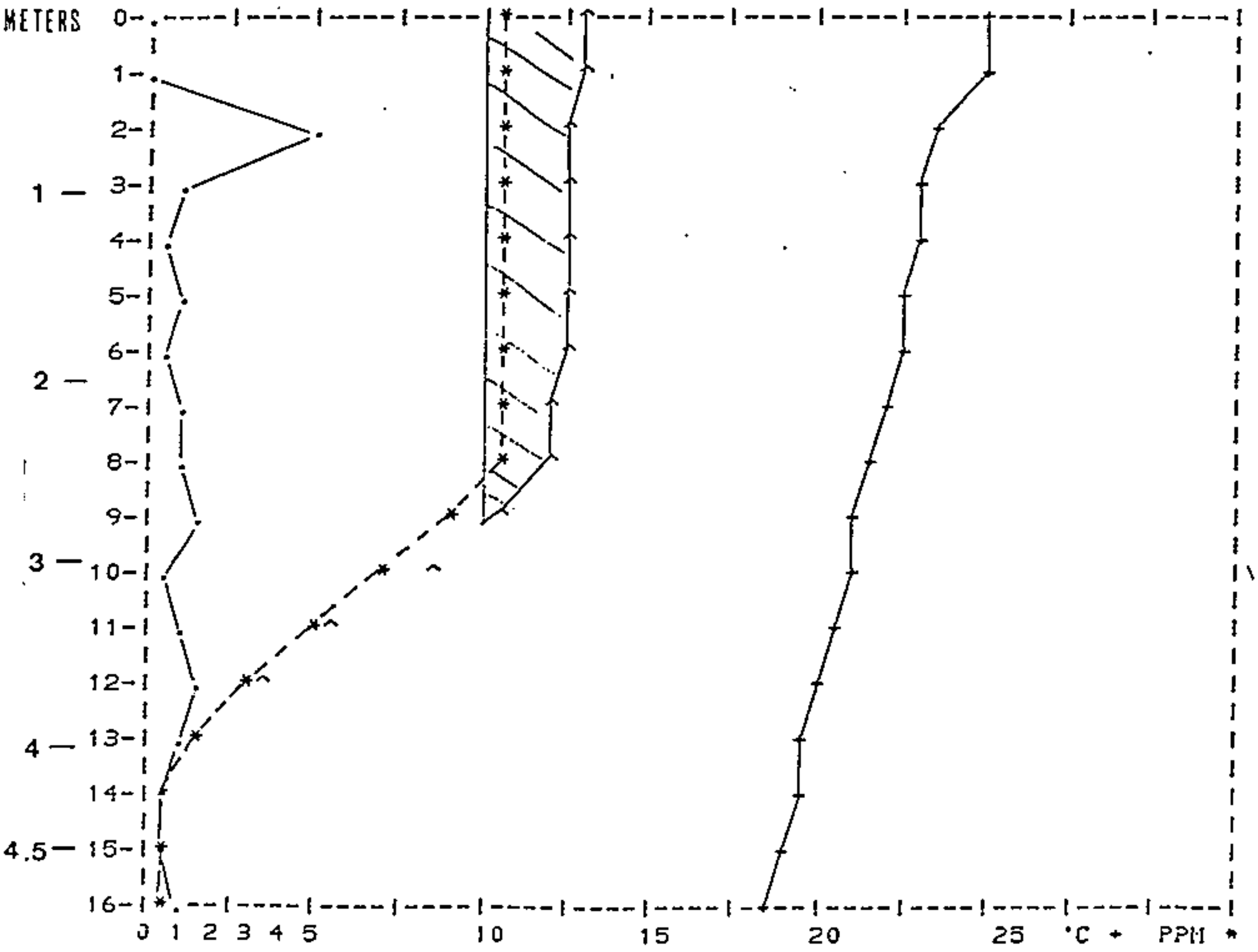


Figure 10

LAKE ROARING BROOK
August 17, 1990
STATION A

SECCHI DEPTH 9.3 FEET
ANOXIC BOUNDARY 13.4 FEET

DEPTH FEET	TEMP °C	DO mg/L	%SAT	RTRM
0.0	25.0	10.4	128	0
1.0	25.0	10.4	128	0
2.0	23.3	10.5	126	52
3.0	23.0	10.5	125	9 61
4.0	22.9	10.5	125	3
5.0	22.5	10.5	124	11
6.0	22.3	10.4	123	6 20
7.0	22.0	10.3	121	9
8.0	21.7	10.3	120	8
9.0	21.1	9.2	106	16 23
10.0	20.9	7.2	83	5
11.0	20.5	4.8	55	10
12.0	20.0	3.2	36	13
13.0	19.6	1.5	17	10 38
14.0	19.3	0.3	3	7
15.0	19.1	0.3	3	5
16.0	18.6	0.3	3	12



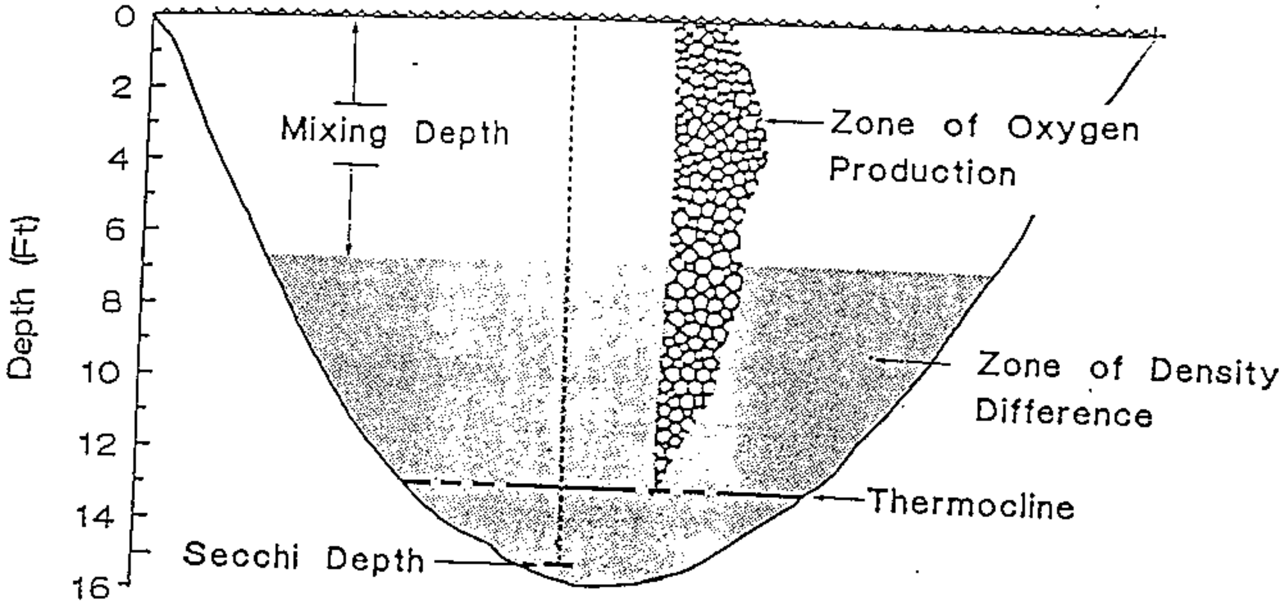
The second profile (taken on August 17, 1991) suggests a weakly stratified condition. RTRM numbers are highest at 1 meter (61) and 4 meters (38). Both these peaks are low in magnitude, but still present enough density difference to form weak thermoclines.

Oxygen loss begins below 2.5 meters (8 ft.) with anoxia below 4 meters (13.4 feet). This area covers about 25 acres (23% of lake area; ca. 6% of the volume). Oxygen production occurs in water up to almost 3 meters (9 feet) with saturation significantly above 100%. The transparency was 2.8 meters (9.3 feet). This again corresponds with the depth of oxygen production, but not as well with density difference.

The lake appears to have very good water transparency allowing for formation of a deep thermocline. The depth of wind mixing can then be a significant portion of the water column. This will allow the lake to completely mix during strong wind events. Weak stratification is still possible as is oxygen loss as well as anoxia. These conditions are based upon the depth to which light currently penetrates (4.6 and 2.8 meters in this study). The Secchi data that we collected is corroborated by those taken by ALS in 1987 (3.3, 3.1 meters; see Figure 12). The Ecoscience report, although presenting no Secchi depths, does show the oxygen production occurred to a depth of 3 meters (10 feet). From the relationship between oxygen production and Secchi depth demonstrated by our data, an estimated Secchi depth of 3.5 meters is probable for the profiles Ecoscience took in 1985 and 1986. The transparency has remained at around 3 meters for the last 5 years, and seems rather stable. It is the governing factor in maintaining limited anoxia development and well oxygenated upper water. It also helps to maintain the clarity of the water by both providing a deeper photosynthetic zone and supplying oxygen to decomposing sediments. The Secchi depth should be watched as part of a local residence program.

Figure 11

Roaring Brook Lake
Profile June 28, 1990



Roaring Brook Lake
Profile August 17, 1990

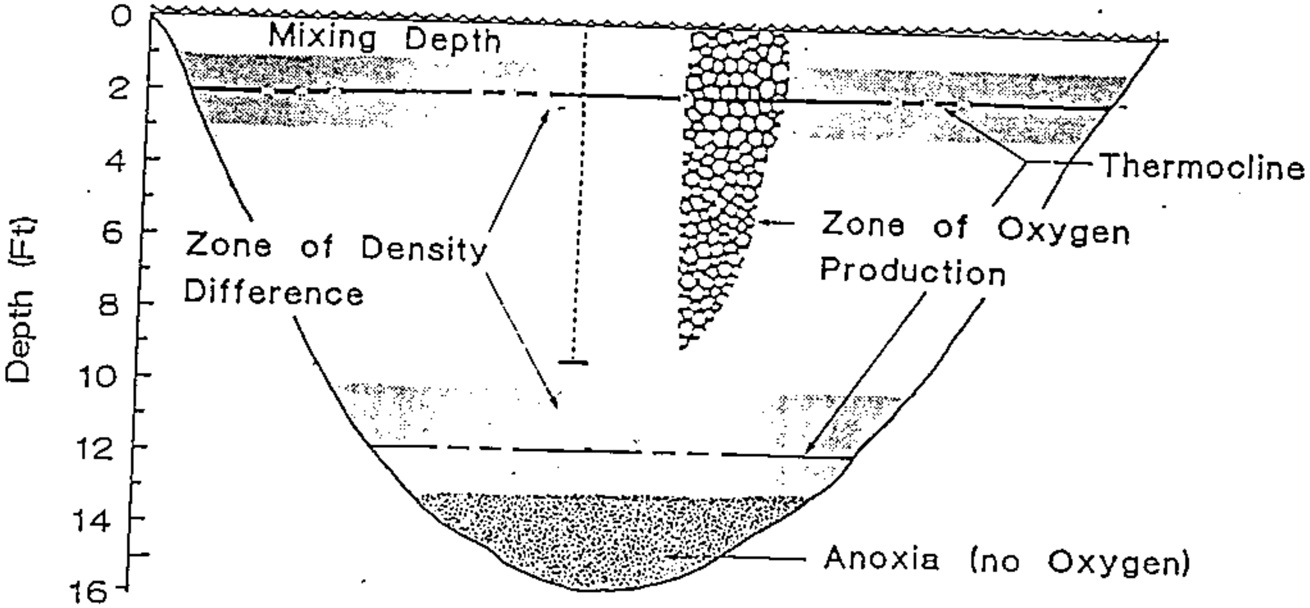
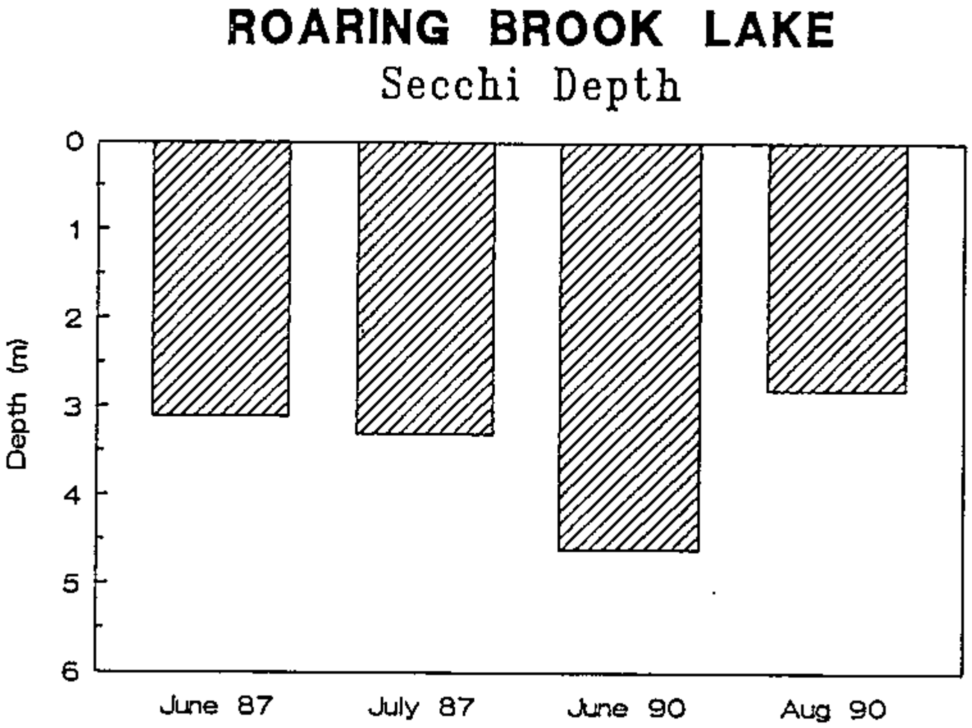


Figure 12


ROARING BROOK LAKE
Secchi Depth
Depth (m)
0
1
2
3
4
5
6
June 87
July 87
June 90
Aug 90

III. C. Lake Profile Chemistry

On the dates that temperature and oxygen profiles were taken at the deep water station, water samples were also collected at various depths for analysis. Table 14 presents the lake profile chemistry results for both dates.

June total phosphorus lake concentrations are indicative of a very high quality water resource. The August concentrations are higher than those in June, but still represent high quality water. Some slight internal nutrient recycling is indicated by the fact that phosphorus is increasing with depth. The 4.5 meter sample on August 17 was taken in water devoid of oxygen and only weak thermal boundaries isolated this anoxia. Phosphorus released from the sediments during this condition may have been diffusing upward in the water column. The ammonia concentrations repeat this pattern of increasing with deeper water. Ammonia concentrations are low, however, and are typical of this type of lake-watershed ecosystem. The conductivity is indicative of a moderately softwater lake. The level of conductivity in the lake dropped between the two dates from a mean of 135 to a mean of 103. This represents a reduction in the amount of dissolved ions in the water and is significant enough to indicate a real change. It suggests that road runoff, generally high in ions, influences lake chemistry early in the year. The pH is normal, averaging just slightly higher than neutral.

Table 14

ROARING BROOK LAKE PROFILE CHEMISTRY

6-28-90

Depth (m)	F.Coli (/100)	TP (ppb)	NO3 (ppb)	NH3 (ppb)	Cond	pH	Temp C	D.O. (mg/L)	% Sat
0	----	10	<50	71	133	7.2	23.0	9.0	107
1	----	----	----	----	----	----	23.0	9.1	109
2	----	----	----	----	----	----	23.0	9.0	107
2.5	----	9	<50	<10	133	7.2	22.0	9.2	107
3	----	----	----	----	----	----	21.0	9.4	108
4.5	----	10	<50	28	138	6.5	15.5	5.0	50

8-17-1990

Depth (m)	F.Coli (/100)	TP (ppb)	NO3 (ppb)	NH3 (ppb)	Cond	pH	Temp C	D.O. (mg/L)	% Sat
0	----	----	----	----	----	----	25	10.4	128
1	----	15	<50	27	105	7.2	23.0	10.5	126
2	----	16	<50	39	104	7.1	22.3	10.4	123
2.5	----	----	----	----	----	----	21.7	10.3	120
3	----	18	<50	50	101	7.1	20.9	7.2	83
4.5	----	21	<50	----	----	----	19.1	0.3	3

II. D. Surface Water Survey -

On June 28, 1990, 9 surface water samples were collected near the shore in order to survey for possible septic problems. The sites are shown in Figure 6 and the results of the testing is presented in Table 15.

The fecal coliform bacteria numbers are low, and all very similar. The values range from a low of < 25/100 mls to 75/100 mls. It is uncertain as to whether there are any real differences between any of the stations based on one data set of surface samples. Although stations 5 and 9 both had 75 colonies/100 mls, these numbers may not represent a statistically significant difference from the other samples. However, it may be indicating that these locations would warrant further testing to determine if higher fecal coliform bacteria levels, in fact, exist in shore areas.

The nutrient phosphorus was found in very low levels throughout, from 6 to 13 ppb. These levels are representative of oligotrophic water quality. Both nitrogen species, ammonia and nitrate/nitrite, were found in low levels. Nitrate was below the detection limit of 50 ppb while ammonia ranged from below 10 ppb to 83 ppb.

The conductivity and pH were very similar throughout the lake. Conductivity ranged from 134 to 139 while pH ranged from 7.2 to 8.5. Station 9 may have had a higher pH value because of the active photosynthesis occurring there. The plants (mostly weeds in this case) remove carbon dioxide from the water and fix it into organic matter. This causes a shift in the carbonate buffering system present in the water in favor of a higher pH value. This photosynthesis activity is also demonstrated by the high dissolved oxygen and % saturation value at station 9.

Table 15

ROARING BROOK SURFACE WATER SURVEY

SITE	F.Coli (/100)	TP (ppb)	NO3 (ppb)	NH3 (ppb)	Cond	pH	Temp C	D.O. (mg/L)	% Sat
1	25	6	<50	<10	134	7.4	23.0	9.5	111
2	50	11	<50	47	136	7.3	23.0	10.0	116
3	25	8	60	27	134	7.3	23.8	9.2	112
4	50	6	<50	<10	134	7.4	23.0	9.8	118
5	75	8	<50	54	135	7.2	24.8	9.6	115
6	25	8	<50	<10	134	7.3	23.5	9.0	106
7	<25	13	<50	83	136	7.2	25.3	9.3	112
8	<25	6	<50	<10	135	7.2	24.2	9.2	109
9	75	10	<50	60	139	8.5	24.4	11.8	141

II.E. Macrophytes

Table 16 and Figure 13 present macrophyte ("weed") species occurring in the littoral zone (shallows) of the Roaring Brook Lake, in general order of observed dominance. Surprisingly (based on previous information), the "nuisance" was not only milfoil, but dense biomass of *Utricularia sp.* (bladderwort). These are very different plant species. The goal of management is *not* to eradicate macrophytes in Roaring Brook Lake, but rather to control recreational and aesthetic *nuisance*. Milfoil is a common nuisance species. It is not endemic (native); hence it will take time for nature to "catch up" with it by establishing a population of grazers to take advantage of the food resource it represents. This appears to be happening in several lakes in the northeast. Essentially, this is analagous to a very fertile field of grass with no cows to control standing crop (not productivity) of the grass. There are effective control methods available for a lake such as Roaring Brook Lake.

TABLE 16

Roaring Brook Lake Macrophytes

Scientific Name	Common Name
Utricularia geminiscapa	Bladderwort
Myriophyllum spicatum	Milfoil
Najas minor	Bushy Pondweed
Ceratophyllum demersum	Coontail
Potamogeton amplifolius	Large-leaf Pondweed
P. pusillus (?)	Pondweed
Nitella flexilis	Muskgrass
Chara sp.	Stonewort

Utricularia sp. is a totally different "critter". It is a "bog indicator" plant and is not particularly limited by phosphorus availability. It has a "carnivorous habit" not unlike the Venus flytrap (for obtaining a source of nitrogen). It is difficult to effectively control by harvesting. Although the scientific literature indicates mixed results with bladderwort control by seasonal lake level management (drawdown), a *well planned* program of this type is likely the best strategy. A "seasonal lake level policy" should be developed which:

- avoids consequential impacts both to the lake *and* downstream,
- optimizes weed control benefit (of *nuisance*), and
- is within the natural limitations of the hydrology, morphometry and ecosystem structure of Roaring Brook Lake.

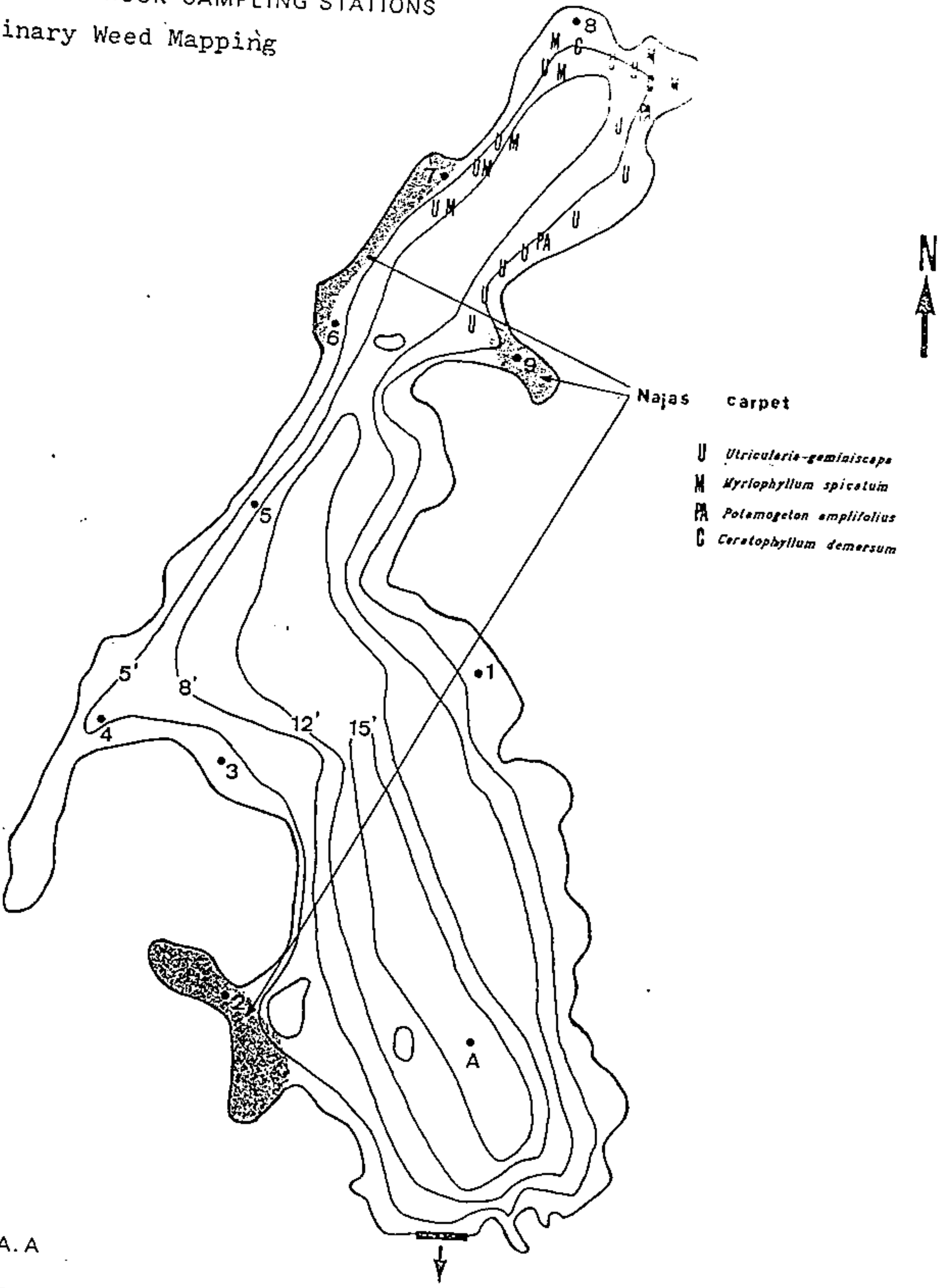
Such an approach can be accomplished at Roaring Brook Lake, and is outlined in preliminary form in the management section of this report.

FIGURE

Figure 13

LOCATION OF ROARING BROOK SAMPLING STATIONS

Preliminary Weed Mapping



BACKGROUND: STA. A

SURFACE GRABS: STAS. 1-9

SCALE: 0' 608'

III. Management Suggestions

The capability to effectively control the nuisance conditions in the Roaring Brook Lake ecosystem is present in the facilities which created the lake; namely, the dam and outlet system.

Effective management of a high quality Roaring Brook Lake resource will involve:

- detailed evaluation of how to use existing facilities for resource quality control while avoiding adverse impacts,
- simple modifications/additions to existing facilities to improve their utility further, and a
- locally-based, long-term monitoring program that is both comprehensive and cost-effective.

The following are methods we believe should not be employed extensively (perhaps on a limited, area-selective basis):

- Chemical Methods including herbicides, algicides, alum, lime, sediment oxidation, ozonation techniques, and bentonite (sediment seal)
- "Biological Perturbations" including sterile grass carp, "forage base fishery enhancement"; planned gamefish stocking is appropriate and desirable (a "creel census program" to estimate the "taking rate" is also desirable).
- "Light Limitation" methods (such as Aquashade) are strongly not recommended. However, benthic barriers, seasonal "light covers", and contained area use of Aquashade in selected high-use areas (e.g. swimming areas) could be beneficial.

Interim: Area-Selective Methods

Harvesting

Long-term management methods will proceed through several stages. The first stage will be refinement, followed by implementation, and then monitoring. During this time, mechanical harvesting will be useful for controlling nuisance conditions. Although we believe alternatives offer better long-term cost-effectiveness, harvesting can provide immediate, [illegible] of macrophytes. If harvesting is continued we recommend the following impact avoidance considerations:

1) Fragmentation (esp. of milfoil) can lead to the spread of dense populations. Removal of a maximum of cut shoots is desirable. Fragmentation should be minimized, even if this results in higher per acre cost.

2) We recommend that about 20% of the lake area less than 10 ft. deep be identified as a "refuge area" and not be harvested. This will provide an adequate biotic refuge for a variety of species. The 20% does not need to be one large area; it is desirable to retain several smaller areas which total 20%. Approximately 70 acres are less than 10 ft. deep; 20% of that = 14 acres. The areas of "Najas Carpet" are a good start to identifying refuge. Additional areas totaling about 15 acres should be selected by the lake users (areas where refuge retention does not interfere with recreational/aesthetic use).

Ultimately, we believe alternative methods will provide more cost-effective long-term control. *Utricularia sp.* will be difficult to control by harvesting; fragmentation of milfoil should be avoided as possible.

Methods which appear to be most appropriate and desirable include:

1) A well planned, controlled program of seasonal lake level management.

2) Depth-selective hydraulic flow routing (entirely by gravity -- no pump or siphon) on a limited basis. This is a desirable low cost option -- not an absolute need. Because of available deep strata flushing rate (>5 times per growing season), anoxia will likely be avoided entirely.

3) Very limited aeration -- essentially to make lake level management work best while avoiding any adverse biotic impact (to avoid winter kill).

4) Implementation of a long-term monitoring/management plan involving local residents.

Each of these general approaches is discussed below.

1) **Seasonal Lake Level Management**
(Preliminary. Detailed plan needed.)

This approach can be effective for milfoil control, and will probably help to control Utricularia sp. nuisance. It must be done in a way which:

- avoids impact to fish community (i.e. winter kill),
- avoids downstream hydraulic impact (flooding during release, low-flow during refill),
- avoids wetland impact, and the
- impact of ice block drift (e.g. on shoreline structures, etc.).

The facilities available, and the nature of the Roaring Brook Lake ecosystem, make this approach desirable.

Approximately 44 acres between the surface and 6 ft. deep could be controlled by exposure. This will substantially control nuisance macrophytes. The volume of this 6 ft. surface layer is about 570 acre-ft. About 307 acre-ft remain below 6 ft. Refill needs to begin at ice-out or slightly before (ca. March 1). Drawdown needs to be early, and stable enough, to allow for winter hibernation of aquatic organisms (e.g. amphibians, turtles, etc.).

Between March 1 and April 15 average runoff is 450 acre-ft. The criteria should be a (nearly) full lake by April 15. Also, during refill, an adequate volume should be continuously released downstream. Based on natural low flow values we would suggest maintenance of about 65 acre-ft per month downstream flow.

Hence, refill water available March 1 - April 15 is about 400 acre-ft. This indicates that the maximum drawdown level or March 1 is about 4 ft. A six-foot drawdown can be employed, but only by bringing the lake back to -4 ft. by March 1. Drawdown will also facilitate individual actions such as debris removal, stump removal, etc.

The following is a preliminary drawdown schedule to illustrate the approach. This is <u>not</u> ready for implementation -- further detailed planning is necessary!

<u>October 15-30</u>: Slowly lower lake level 5 ft., stabilize between -5 and -6 feet.

Normal outflow at this time averages 75-135 acre-ft/mo. Release at a steady rate of about 300 acre-ft/mo. will reach the -5 ft. level by Thanksgiving while avoiding downstream flooding or streambank cuts (i.e. streambed now experiences 312 ac-ft per month in April).

<u>February 1</u>: Begin refill to -4 ft. by March 1.

In this interval, normal inflow is about 162 ac-ft. Allowing adequate downstream flow (ca. 62 ac-ft/mo.) refills 100 ac-ft of lake void, raising it to -4 ft.

<u>March 1</u>: Begin total refill, allowing 65 acre-ft/mo downstream flow to continue.

March + April Runoff = 619 ac-ft
Minus downstream flow = 130 ac-ft

Refill Volume = 489 ac-ft

0-4 ft. Volume = ca. 376 ac-ft

Refill Time Needed:
376/489 = 77% of March & April
= ca. 47 days

Full by approximately April 16 while allowing adequate downstream flow.

This "preliminary schedule" is intended only to exemplify how such a program would work with minimum impact potential. Refinement, perhaps developing an actual rain-runoff basis, and verification of bathymetry, should be done prior to establishing policy. Seasonal drawdown would also facilitate maintenance work in shoreline areas (such as wall/dock repairs, bottom clean-up, stump/obstruction/debris removal, etc.).

Facilities/Potential Impacts

Several impacts have been discussed and avoided (e.g. flooding and low-flow downstream). A detailed inspection/evaluation should be done to determine possible ways to facilitate an environmentally sound approach such as:

i) Adding a small, low-flow orifice which ensures a minimum low-flow downstream at all times automatically.

ii) A procedure or structure for stabilizing all design criteria levels (e.g. -5 ft., -4 ft., and continuous low flow).

* No significant contiguous wetland ecosystems would be damaged; the watershed wetlands are upgradient of the lake.

* It is not likely that wells will be effected by the described program, but this should be considered further by conducting a lakefront resident survey.

* Fishery impacts will need to be avoided. At the maximum drawdown level of -6 ft., only about 68 acres/300 acre-ft of lake remain. This could result in an under-ice winter kill due to anoxia. Implementation would likely require a small aeration/deicing system. Cost (total) would be less than $8,000 for a "multiple operation" system (for winter and summer); less to simply "deice" in winter.

It should be noted that "drawdown" was initially developed as a fishery management method. It concentrates prey items and increases gamefish growth rates. It also decreases zooplanktivorous fish species population size and young-of-year size classes (a "biomanipulation" method). If potential winter kill is avoided, the method will likely have net benefits to the fishery.

2) Depth-Selective Hydraulic Flow Routing

The maximum anoxic volume is about 50 acre-ft. This could be "flushed" more than seven times during summer stratification. This would probably eliminate all oxygen loss, and have net benefits year-long. Costs depend on a detailed evaluation of existing structures, but are likely to be less than $9,500 total. It may be possible to integrate this with the previously described "low-flow orifice", providing a consistent, high quality, cold downstream flow (e.g. flow augmentation function).

3) **Aeration** is not needed to solve an existing internal loading problem. However, it is likely needed to make lake level management work optimally without adverse impact (e.g. deicing). It would be cost-effective to install a system for the primary function (winter) and for bottom strata aeration for habitat improvement in summer. Such a "multiple use" aeration system would cost about $8,000 (total).

4) A long-term monitoring plan with local involvement is recommended. A local sampling program can develop a long-term database for identifying eutrophication trends.

IV. Conclusions/Recommendations

Of the available lake management methods, the following appear to be "best" for Roaring Brook Lake:

1) Develop a citizen monitoring program with professional assistance.

2) Prepare a long-term lake preservation plan (i.e. Watershed Management Plan). Incorporate such elements as:

   * Septic System Maintenance Guidelines,

   * Fertilization Methods Guidelines,

   * Landscaping Guidelines for the Shoreline,

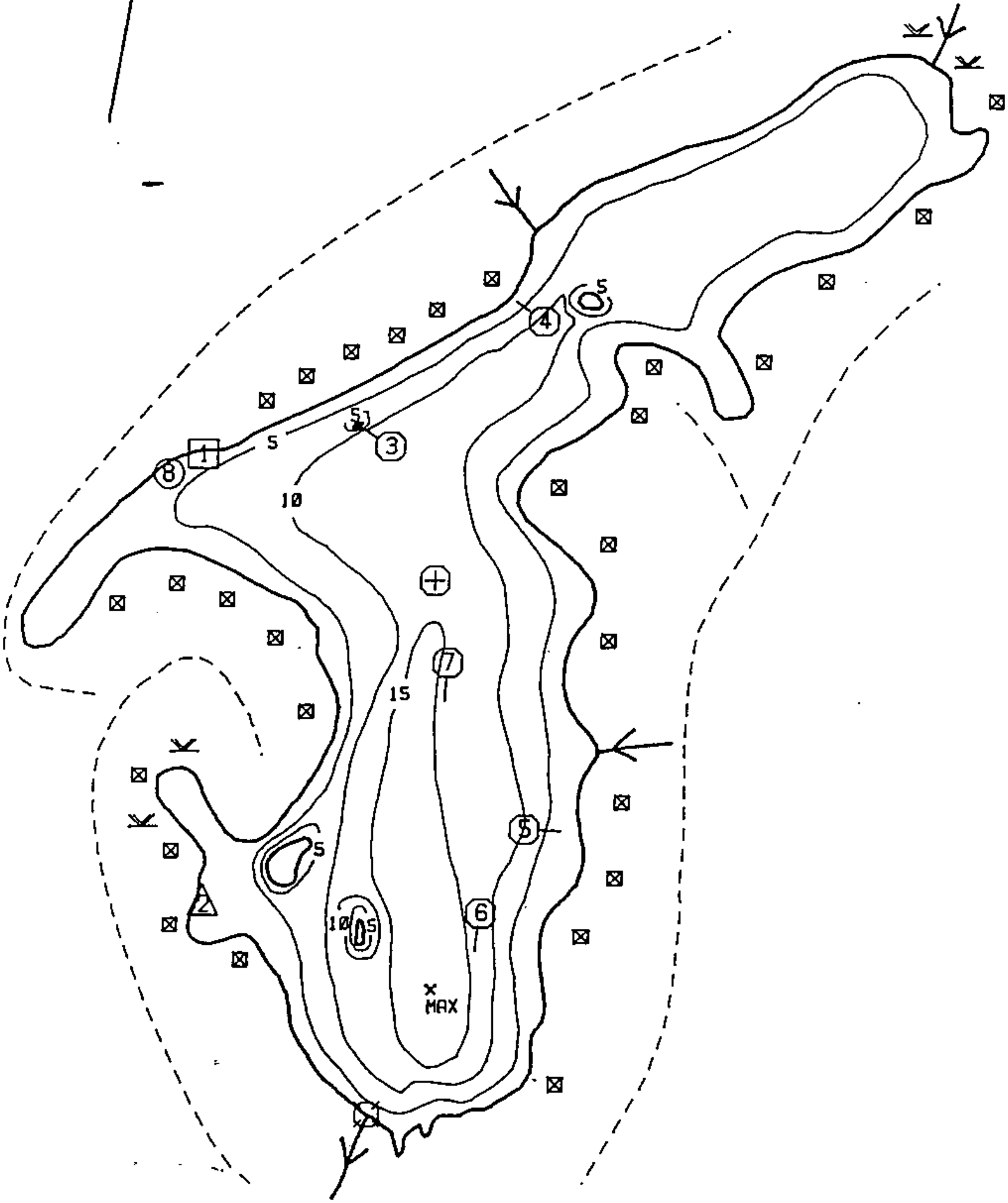
   * Stormwater Management Methods which will be effective and practical at Roaring Brook Lake.

3) Develop and Implement a detailed seasonal lake level management policy. Test the approach in a multi-year phased implementation approach to monitor both effectiveness and potential impacts. Start with a modest drawdown program and proceed as monitoring dictates. A small-scale deicing system will likely be needed if more than 30% of the lake area is to be exposed (ca. 4-5 ft. drawdown).

4) If a drawdown is implemented (phased program), a low flow orifice should be included to sustain downstream flow at all times (ca. 60-65 ac-ft/mo = 1.14 cfs). A low flow rate of 1.14 cfs is adequate to flush the volume which typically experiences oxygen loss once per summer month. Hence, the low-flow orifice could be used for bottom "depth-selective outflow" while maintaining high quality downstream flow.

5) While phasing in a drawdown policy (with citizen monitoring), an area-selective harvesting plan should be used to control "nuisance" created by excessive macrophyte abundance.

1



ROARING BROOK LAKE

1301838
ECOSCIENCE REVISED 1987
CONTOUR INTERVAL: 5 FT
SURFACE AREA: 117 ACRES
MAXIMUM DEPTH: 18 FT

├ 600' ┤
MARSH/WETLAND
☒ DWELLING
-- ROAD/TRAIL
CONTROLLABLE DAM

6/9/87
WATER CHEMISTRY
150 FT GILL NET
30 FT MINNOW NET
□ MINNOW TRAP
○ BEACH SEINE

ROARING BROOK LAKE
130183B (LH)

```
***********************
* LOCATION and STATUS *
***********************
```

Latitude:	412559
Longitude:	734823
Elevation:	236 m
Quadrangle:	P252 OSCAWANA
County:	PUTNAM
Ownership:	PRIVATE
Posting:	POSTED

Access

Type	Owner-ship	Posted Status	Distance To Road	Road Class
ROAD	PRIVATE	POSTED	0.0 km	2 WHEEL DR

Boat Access

Type: BEACH LAUNCH-VEHICLE
Ownership: PRIVATE

General Watershed Characteristics(%)

Deciduous Forest:	20
Coniferous Forest:	
Decid-Conif Mix:	5
Shrub-Sapling Area:	10
Wetland:	
Open Grass:	
Agricultural:	
Developed:	65

Immediate Shoreline Characteristics(%)

Deciduous Forest:	15
Coniferous Forest:	
Decid-Conif Mix:	5
Shrub-Sapling Area:	10
Wetland:	2
Open Grass:	
Agricultural:	
Developed:	68
Sand-Gravel Beach:	
Boulder Rock Ledge:	

```
ROARING BROOK LAKE                                   *****************
130183B  (LH)                                        * MORPHOMETRICS *
                                                     *****************

Area:            Surface(SA):  47.3   ha
====           Watershed(WA):  453.6  ha
               Littoral Zone:  31.3   ha
                SA/WA Ratio:   .10

Depth:                 Mean:   2.4   m
=====                   Max:   5.5   m

                     Volume:   1124254   m3
          Shoreline Length:    5.5   km
       Mean Annual Runoff:     56   cm
            Flushing Rate:     2.3   times/year
  Shoreline Slope <5 deg.:     15   %


                 Shoalwater Substrate(%)
                 =======================

                    Boulder:  35
                     Rubble:   5
                       Sand:  20
                 Muck/Silt:   20
                   Organic:   20

Date: 06/09/1987

Inlet:
=====
       1    Estimated Flow:   NOT MEASURED
       2    Estimated Flow:   NOT MEASURED
       3    Estimated Flow:   NOT MEASURED

Outlet:
======
       1    Estimated Flow:   NOT MEASURED
                Outlet Dam:   YES
              Controllable:   YES
                 Structure:   OTHER
                  Material:   OTHER
               Head Height:   3.8   m


Remarks:
06/09 POND COMPLETELY SURROUNDED BY HOUSES, TOO NUMEROUS
      TO SHOW ON MAP.  INLETS AND OUTLET IMMEASURABLE.
      INLETS HAD LOW DIFFUSE FLOW, OUTLET HAD DIFFUSE FLOW.
      OUTLET EARTHEN DAM WITH CONCRETE SPILLWAY.
```

ROARING BROOK LAKE
130183B (LH)

```
*****************
* INVERTEBRATES *
*  MACROPHYTES  *
*****************
```

MacroInvertebrates

Date: 06/09/1987

Method: D-FRAME DIP NET

Phylum	Class	Order	Family
ANNELIDA	OLIGOCHAE	UNSPECIFIED	UNSPECIFIED
ARTHROPODA	CRUSTACEA	ISOPODA	UNSPECIFIED
		AMPHIPODA	UNSPECIFIED
	INSECTA	EPHEMEROPTERA	EPHEMERELLIDAE
		ODONATA	COENAGRIIDAE

Aquatic Macrophytes

Date: 06/09/1987

Type(%)	
Emergent vegetation:	0
Submergent vegetation:	40
Floating vegetation:	0
Open water:	99

Species

TYPHA spp.
POTAMOGETON spp.
PHRAGMITES spp.
CERATOPHYLLUM spp.
LYTHRUM spp.
MYRIOPHYLLUM spp.
ALGAE-NUMEROUS TAXA

Date: 07/15/1987

Type(%)	
Emergent vegetation:	1
Submergent vegetation:	0
Floating vegetation:	0
Open water:	99

ROARING BROOK LAKE
130183B (LH)

****
* INVERTEBRATES *
* MACROPHYTES *
****

Aquatic Macrophytes

Species

- TYPHA spp.
- POTAMOGETON spp.
- PHRAGMITES spp.
- LYTHRUM spp.
- MYRIOPHYLLUM spp.
- ALGAE-NUMEROUS TAXA

ROARING BROOK LAKE
130183B (LH)

****
* FISHERIES SUMMARY *
****

Date: 06/09/1987

Station: 1 M-TRAP .25" METAL 22.9 hrs
=========== DEPTH SET: .9 m

Species	#	Total Wt (g)	Length Range (mm)
NO FISH CAPTURED			

Station: 2 MONO G-NET 30' 19.8 hrs
=========== MIN DEPTH: .4 m MAX DEPTH: .9 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	3	420	229 - 233
PUMPKINSEED	1	100	171 - 171

Station: 3 E-S GILL NET 150' 19.8 hrs
=========== MIN DEPTH: .6 m MAX DEPTH: 3.6 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	6	744	228 - 234
WHITE SUCKER	2	2240	403 - 462
WHITE CATFISH	1	620	344 - 344
WHITE PERCH	1	250	256 - 256
PUMPKINSEED	3	305	154 - 185
LARGEMOUTH BASS	2	830	268 - 357
BLACK CRAPPIE	8	1320	215 - 234
YELLOW PERCH	11	908	181 - 226

ROARING BROOK LAKE
130183B (LH)

****
* FISHERIES SUMMARY *
****

Date: 06/09/1987

Station: 4 E-S GILL NET 150' 19.2 hrs
=========== MIN DEPTH: 1.0 m MAX DEPTH: 3.4 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	15	1690	200 - 244
WHITE SUCKER	1	390	310 - 310
WHITE CATFISH	1	1500	420 - 420
WHITE PERCH	4	820	232 - 250
PUMPKINSEED	12	935	148 - 178
LARGEMOUTH BASS	4	710	170 - 310
BLACK CRAPPIE	5	670	206 - 231
YELLOW PERCH	34	2800	162 - 219

Station: 5 E-S GILL NET 150' 19.8 hrs
=========== MIN DEPTH: 1.0 m MAX DEPTH: 3.6 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	6	900	*
WHITE SUCKER	1	860	398 - 398
WHITE CATFISH	1	340	301 - 301
WHITE PERCH	2	410	239 - 250
PUMPKINSEED	7	600	*
LARGEMOUTH BASS	3	590	244 - 254
BLACK CRAPPIE	11	1606	210 - 220
YELLOW PERCH	8	1000	*

ROARING BROOK LAKE
130183B (LH)

****
* FISHERIES SUMMARY *
****

Date: 06/09/1987

Station: 6 E-S GILL NET 150' 19.9 hrs
=========== MIN DEPTH: 4.3 m MAX DEPTH: 4.5 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	13	2000	*
WHITE SUCKER	1	1600	464 - 464
PUMPKINSEED	3	285	*
YELLOW PERCH	25	2500	*

Station: 7 E-S GILL NET 150' 19.9 hrs
=========== MIN DEPTH: 3.6 m MAX DEPTH: 4.3 m

Species	#	Total Wt (g)	Length Range (mm)
GOLDEN SHINER	3	450	224 - 240
WHITE SUCKER	1	1800	479 - 479
WHITE CATFISH	1	600	341 - 341
WHITE PERCH	2	380	226 - 253
PUMPKINSEED	2	160	154 - 154
YELLOW PERCH	17	1600	*

Station: 8 BEACH SEINE .2 hrs
=========== MAX DEPTH: 1.2 m

Species	#	Total Wt (g)	Length Range (mm)
PUMPKINSEED	9	595	135 - 170
LARGEMOUTH BASS	2	40	116 - 124

ROARING BROOK LAKE
130183B (LH)

****
* FISHERIES SUMMARY *
****

CATCH PER UNIT EFFORT (#/Hour) BY SPECIES AND GEAR TYPE

Species	150 Ft Gill Net	30 Ft Minnow Net	Minnow Trap
GOLDEN SHINER	.44	.15	0.00
WHITE SUCKER	.06	0.00	0.00
WHITE CATFISH	.04	0.00	0.00
WHITE PERCH	.09	0.00	0.00
PUMPKINSEED	.27	.05	0.00
LARGEMOUTH BASS	.09	0.00	0.00
BLACK CRAPPIE	.24	0.00	0.00
YELLOW PERCH	.96	0.00	0.00
Hours Set	98.6	19.8	22.9

Remarks:
06/09 ONE SEINE HAUL COMPLETED. NO NETS SET IN NORTHERN PORTION OF LAKE DUE TO OPERATION OF A WEED HARVESTER.

ROARING BROOK LAKE
130183B (LH)

****
* CHEM/PHYS PARAMETERS *
****

DATE(1987)	06/10	07/15
STATION	9	1
DEPTH(m)	1.5	1.5
PHYS/CHEM DATA		
FIELD pH	6.72	6.20
LAB pH	7.44	7.94
AIR EQ pH	7.38	7.61
ANC (ueq/l)	298.4	335.6
DIC (mg/l-C)	4.31	4.44
DOC (mg/l-C)	5.5	4.3
LAB (Pt-Co)	20	15
FIELD (Pt-Co)	30	45
VISUAL COLOR	YL-BRN	YL-BRN
SECCHI DEPTH(m)	3.1	3.3
SP. COND (25 C) (umhos/cm)	117.2	122.2
ANIONS (mg/l)		
SIO2	LTD	.2
SO4	8.64	8.32
NO3-N	LTD	LTD
CL	20.26	19.64
F	.054	.048
TOTAL P1		.013
TOTAL P2	.032	.038
CATIONS (mg/l)		
NH4-N	LTD	LTD☆
CA	8.75	9.07
MG	2.31	2.48
NA	8.11	7.75
K	1.07	.98
TRACE METALS (mg/l)		
AL	.047	.023
FE	.153	.066
MN	.176	.026
PB	LTD	LTD
ZN	.005	.004
CU	.002	.002

LTD - Less than detection

☆ - Not analyzed within holding time

★ - Secchi measured on bottom